Study Group 4

ELECTRONIC FUNDAMENTALS

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

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Theory Lesson 7

INTRODUCTION

As you learned in Theory Lesson 5, resistance is the property of a circuit that opposes the flow of current in the circuit. Because all electrical circuits have some resistance, no matter how small the amount, it is important that we know what resistance does in a circuit and how we may use it to work for us.

When electric current overcomes the opposition of resistance and flows in a circuit, heat is produced. So, one way in which we use resistance is to produce heat. Electric toasters, electric heaters, and most electric stoves produce heat by having electric current flow through circuits containing resistance. For example, the spiral of wire that glows in an electric heater is nothing but a wirewound resistor.

Resistance is used in many other ways in electrical circuits. Before we study these other uses of resistors, let's learn about resistors themselves.

7-1. RESISTORS

In Theory Lesson 5, we found that

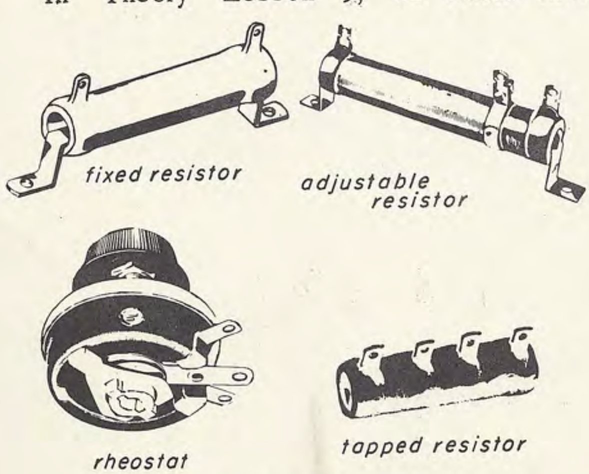


Fig. 7-1

a resistor is a part that is made so as to offer resistance to the flow of current when it is placed in an electric circuit. Resistors may be divided into two main classes: *wirewound* and *carbon composition.*

Wirewound Resistors. Wirewound resistors are made from a metal wire or a metal ribbon wound on a glass, ceramic, plastic, or fiber form. In general, wirewound resistors are used to handle high current or large amounts of power, or where great accuracy in the resistance value is important. Wirewound resistors come in several types, as shown in Fig. 7-1.

In one type, the *fixed resistor,* resistance remains the same under normal working conditions.

An *adjustable resistor* has a sliding tap or terminal that permits the resistance to be adjusted to the amount desired. Once adjusted, the resistance of such a resistor, under normal working conditions, remains the same until readjusted.

A *variable resistor,* which we usually call a *rheostat,* is one that has a sliding contact arm, normally attached to a shaft and knob. Rheostats normally have two terminals, one of which is connected to the sliding arm and the other to one end of the resistor. By turning the knob, the resistance of the rheostat may be readily set at the desired value.

A *tapped resistor* has fixed taps or terminals that divide the value of the total resistor into two or more fixed amounts. Such a resistor takes the place of two or more fixed resistors connected in series.

Carbon Composition Resistors. Carbon composition resistors are made from a composition that contains large amounts of graphite or some other form of carbon. This

composition may be formed into short lengths of rod with a wire lead wrapped around each end, as shown in Fig. 7-2*a*. Another way to make carbon composition resistors is to place a certain amount of the carbon composition or graphite in a short length of ceramic tubing. Lead wires are inserted in each end and the ends are then sealed as shown in Fig. 7-2*b*. *Variable* carbon composition resistors with a sliding contact are made in much the same way that wirewound variable resistors are made.

Carbon composition resistors are used in many places in radio and television where great accuracy in resistance value is unimportant, where small amounts of current flow, or where very high values of resistance are needed.

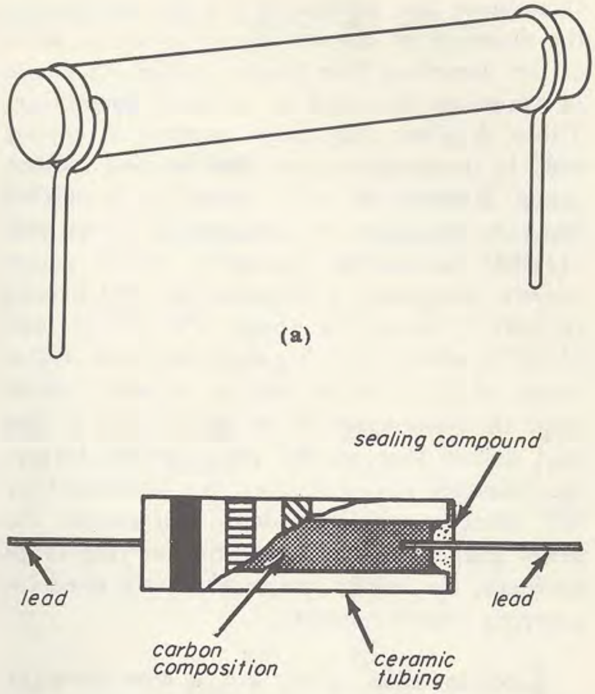
7-2. FACTORS THAT DETERMINE RESISTANCE

As you know, all substances and, therefore, all parts of an electric circuit have resistance. There are three major factors that determine resistance. These are:

1. The length of the material
2. The diameter of the material
3. The kind of material

For example, we use copper wire as a conductor of electricity in circuits. Any length of copper wire offers resistance to the flow of electric current. If we double the length of wire, using wire of the same diameter, we double the amount of resistance. If we triple the length, we have three times the resistance. So we say that *the resistance of a material, such as copper wire, is in proportion to its length.* Which means simply that the longer the wire is, the more resistance it has.

The next factor that determines resistance is the diameter of the substance. A fine copper wire offers more resistance than a thick copper wire. You have seen a similar condition in water hoses. For example, a hose used for sprinkling the lawn offers much more resistance to the flow of water than a hose of larger diameter used by firemen to



(a)

cutaway view of ceramic cased carbon composition resistor

(b)

Fig. 7-2

put out fires. Therefore, the flow of water through the garden hose is at a much slower rate than that through the fire hose. In much the same way, the larger the diameter of a copper wire, the less is the resistance, and the greater is the amount of current it can safely pass. From this we can see that as the diameter of the wire grows smaller, the resistance increases, and as the diameter grows larger, the resistance decreases. So we say that *the resistance of a substance, such as copper wire, is in inverse proportion to the area of that substance.*

When we say that two quantities are in proportion, we mean that as one quantity increases the other quantity increases, both at a fixed rate. When we say that two quantities are in inverse proportion, we mean that as one quantity increases, the other quantity decreases, both at a fixed rate.

Resistance varies inversely with the square of the diameter

Wire Gauges. The diameter of copper wire is measured by different standards

throughout the world. In the United States, the diameter of copper wire is given in units of the American Wire Gauge (AWG). A *gauge* is a standard by which we measure something. Table A gives the gauge number of copper wire in the first column. The second column gives diameter in *mils*. A mil is a unit of measure equal to one-thousandth of an inch (1/1000"). So, for instance, No. 1 gauge copper wire has a diameter of 289.3 mils (0.2893"), which is about 3/10 of an inch (3/10"), while No. 10 gauge wire has a diameter of 101.9 mils, which is just a little more than one-tenth of an inch (1/10"). You will notice that as the gauge grows larger, the diameter grows smaller. So, because they are thicker and offer less resistance, the lower gauge wires are used for carrying large currents; the higher gauge wires are used for carrying small currents.

Circular Mils. If we cut a wire straight across, as shown in Fig. 7-3*a*, we can see the *cross-section* of the wire, as shown in Fig. 7-3*b*. The cross section of a wire is the flat area that appears when a vertical cut is made at right angles to the length of the wire. Because, the cross-sectional area is circular in all circular wires, it is sometimes more convenient to use a circular measure when we speak of this area. So, we use a unit called the *circular mil*. A *circular mil* is equal to the area of a circle that has a diameter of 1 mil (1/1000"). To find the cross-sectional area of a wire in circular mils, we multiply the diameter of the wire, in mils, by itself. For example, the diameter of No. 36 wire is 5 mils. Multiplying 5 times 5, we find that the area is 25 circular mils.

The third column in Table A shows that the area of No. 10 gauge wire is equal to 10,380 circular mils, while the cross-sectional area of No. 20 gauge wire is equal to only only 1,022 circular mils.

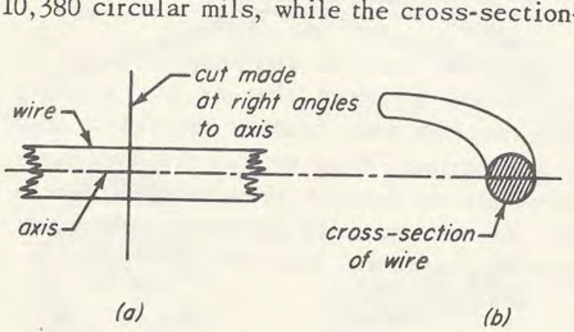


Fig. 7-3

Specific Resistance. We compare the resistance of one material with another material by using a unit called the *circular-mil-foot*, or sometimes *mil-foot*.

A circular-mil-foot of wire is equal to a wire with a diameter of one mil, one foot long. So, to compare resistance of silver and resistance of copper, we measure the resistance of a circular-mil-foot of silver and the resistance of a circular-mil-foot of copper. We call the resistance of a circular-mil-foot of any substance the *specific resistance* of the substance. Table B shows that the specific resistance of silver is 9.88 ohms and the specific resistance of copper is 10.4 ohms. On the other hand, the specific resistance of lampblack is 18,000 – 22,000 ohms and that of graphite is 2,500 – 8,000 ohms.

Let's see how we can use the specific resistance of copper to find the total resistance of a ten-foot length of No. 36 copper wire. To find the resistance, we use this formula:

$$\text{Resistance} = \frac{\text{length (ft) x specific resistance}}{\text{area (in cir mils)}}$$

Looking at Table B, we find that the specific resistance of copper is 10.4 (which is an approximate figure). Looking at Table A, we find that the cross-sectional area of No. 36 copper wire is 25 circular mils. So:

$$\text{Resistance} = \frac{10 \times 10.4}{25} = 4.16 \text{ ohms}$$

DOUBLE DIAMETER – RESISTANCE ÷ 4

Temperature Versus Resistance. You will notice that the table of specific resistance gives each value, in ohms per circular-mil-foot, at 20° centigrade (68°F), which is normal room temperature. Earlier in this lesson, it was said that the three major factors that govern the resistance of a material are length, diameter, and the kind of material. Another factor that has some effect upon the resistance of a material is temperature. The resistance of most metals increases with an increase in temperature and decreases with

TABLE A – BARE COPPER WIRE, AMERICAN WIRE GAUGE AT 20° C.

Wire Size (AWG)	Diameter (Mils)	Cross-Section Area (Circular Mils)	Ohms per 1,000 ft.
0000	460	211,600	0.04901
000	410	167,800	0.06180
00	364.8	133,100	0.07793
0	324.9	105,500	0.09827
1	289.3	83,700	0.1239
2	257.6	66,400	0.1563
3	229.4	52,600	0.1972
4	204.3	41,700	0.2485
5	181.9	33,100	0.3133
6	162.0	26,250	0.3951
7	144.3	20,820	0.4982
8	128.5	16,510	0.6282
9	114.4	13,090	0.7921
10	101.9	10,380	0.9989
11	90.7	8,230	1.260
12	80.8	6,530	1.588
13	72.0	5,180	2.003
14	64.1	4,110	2.525
15	57.1	3,257	3.184
16	50.8	2,583	4.016
17	45.3	2,048	5.064
18	40.3	1,624	6.385
19	35.89	1,288	8.051
20	31.96	1,022	10.15
21	28.46	810	12.80
22	25.35	642	16.14
23	22.57	509	20.36
24	20.10	404	25.67
25	17.90	320.4	32.37
26	15.94	254.1	40.81
27	14.20	201.5	51.47
28	12.64	159.8	64.90
29	11.26	126.7	81.83
30	10.03	100.5	103.2
31	8.928	79.70	130.1
32	7.950	63.21	164.1
33	7.080	50.13	206.9
34	6.305	39.75	260.9
35	5.615	31.52	329.0
36	5.000	25.00	414.8
37	4.453	19.83	532.1
38	3.965	15.72	659.6
39	3.531	12.47	831.8
40	3.145	9.888	1049.0
41	2.75	7.5625	1370.0
42	2.50	6.2500	1,660.0
43	2.25	5.0625	2,050.0
44	2.00	4.0000	2,600.0
45	1.75	3.0625	3,390.0
46	1.50	2.2500	4,610.0

a decrease in temperature. On the other hand, the resistance of some carbons and electrolytes decreases with a rise in temperature and increases with a drop in temperature.

We can find the resistance of a length of conducting material by using the formula:

$$R = R_O \; [1 \pm (a \times t)]$$

where:

R = resistance at temperature other than 20° C.

R_O = resistance at 20° C.

a = temperature coefficient per degree C.

t = degrees of temperature change

In using this formula, the product of a times t is added to 1 when the new temperature is higher than 20 degrees centigrade, and is subtracted from 1 when the new temperature is less than 20 degrees centigrade.

For example, we can find the resistance of 10 feet of No. 36 copper wire at 70° C. Table A shows that 1,000 feet of No. 36 copper wire has a resistance of 414.8 ohms; therefore 10 feet will have a resistance of 4.15 ohms. Table B shows that the temperature coefficient of copper is 0.0039. We find the resistance at 70° C.:

$$\begin{aligned} R &= R_o \; [1 + (a \times t)] \\ &= 4.15 \; [1 + (0.0039 \times 50)] \\ &= 4.15 \; [1 + 0.195] \\ &= 4.15 \times 1.195 \\ &= 4.96 \text{ ohms} \end{aligned}$$

The resistance of the same length of wire at −10° C. is found:

$$\begin{aligned} R &= R_o \; [1 - (a \times t)] \\ &= 4.15 \; [1 - (0.0039 \times 30)] \\ &= 4.15 \; [1 - 0.117] \\ &= 4.15 \times 0.883 \\ &= 3.66 \text{ ohms} \end{aligned}$$

Resistive Materials. Because copper and silver each have a very low specific resistance, they are very seldom used as resistors, except when very low values of resistance are needed. Instead, as you know, graphite and other carbons are widely used in making resistors because each has such a high specific resistance. In making wire-wound resistors, we use metals selected for their resistivity. We call them resistive metals because they offer relatively high resistance for each circular-mil-foot. Table B shows that German silver, iron, and mercury are much more resistive than copper. In addition, certain alloys such as Advance, Eureka, Excello, Nichrome, and others are manufactured specially for making resistors. For example, one circular-mil-foot of Nichrome is over sixty times more resistive than a circular-mil-foot of copper.

7-3. CONDUCTANCE

Conductance is a circuit property that permits the flow of current. It is, therefore, a measure of the ease with which a material or circuit part permits the flow of current. It is, of course, just the opposite of resistance and is found by dividing 1 by the resistance. The answer is given in *mhos;* mho is ohm spelled backwards.

$$\text{Conductance} = \frac{1}{\text{resistance (in ohms)}} = \text{mhos}$$

For example, if a power line has a resistance of 5 ohms we find its conductance by dividing 1 by 5, which gives us 0.2 mho as the conductance:

$$\text{Conductance} = \frac{1}{5} = 0.2 \text{ mho}$$

Materials that allow a free flow of electricity are used as conductors of electricity. Copper, which is second only to silver in its ability to conduct electricity, is widely used to transmit electricity from electric power generators to our homes. As we know, when electricity overcomes resistance in a conductor, heat is produced. So, the people who supply us with electric power use copper wire because they don't want to waste electric power in producing unwanted heat. They choose copper for its *conductance*.

7-4. INSULATORS

To prevent electric currents from flowing, except where we want them to flow, we use insulators. The ideal insulator is one that permits no current to flow, no matter how high the electrical pressure is. There is no such material, because every known material permits some free electrons to pass from atom to atom, even though the number may be very small. However, certain materials, such as glass, mica, porcelain, and so on, permit the passage of so few electrons that, under normal working voltages, the current is so small that we can ignore it.

TABLE B – TABLE OF SPECIFIC RESISTANCE AND TEMPERATURE COEFFICIENT OF CONDUCTING MATERIALS AT 20° CENTIGRADE

Conducting Material	Specific Resistance, Ohms per Cir-mil-foot	Temperature Coefficient per degree Centigrade
Advance	295	0.000018
Aluminum	17.1	0.004
Brass	40.6	0.002
Cadmium	46.0	0.0038
Carbon (lampblack)	18k-22k	0.0004*
Carbon (gas)	30k	0.0005
Carbon (graphite)	2.5k-8k	0.0003*
Climax	480-530	0.0007
Copper	10.4	0.0039
Excello	560	0.00016
German Silver	200-295	0.0004
Gold	14.7	0.0034
Iron (cast)	58.2	0.006
Lead	133	0.0042
Magnesium	27.8	0.004
Manganin	270	0.00002
Mercury	570	0.00089
Monel Metal	289	0.002
Nichrome	676	0.00017
Nickel	52.5	0.0047
Nickel Silver	166	0.00026
Phosphor Bronze	56.7	
Platinum	64.1	0.0038
Silver	9.88	0.004
Steel	79-132	0.0016-0.0042
Tin	69.7	0.0042
Tungsten	33.8	0.0045
Zinc	35.4	0.0037

*Negative temperature coefficient varies with type and source. Figures are approximate.

7-5. BREAKDOWN VOLTAGES

Of course, some materials make better insulators than others because they have fewer free electrons or can withstand the pressures of higher voltages. However, any insulating material acts as a nonconductor of electricity until the electrical pressure becomes high enough. When the voltage rises to the point that we call the *breakdown voltage*, the insulating material will act as a conductor. The reason is that as the voltage rises, the velocity, or speed of movement, of the electrons around the nucleus is so great that electrons are torn away from the atoms of the insulator, and current flows. When this happens, sparking and heat are usually produced. As a result, conducting paths may be burned through the insulator. For example, waxed paper is sometimes used as an insulator. When the voltage becomes high enough, the breakdown point of the paper is reached, and the flow of current burns small holes through the paper. As a result of the sparking and burning, the paper becomes carbonized (charred) and forms conducting paths that will then permit the flow of electric current at voltages much below the breakdown voltage. Even hard materials, such as glass, porcelain, and mica, may crack and form a conducting path.

Table C shows the breakdown voltages of some of the materials used as insulators. It shows the electrical pressure, in volts, necessary to break down these materials for each thousandth of an inch in thickness. For example, if electrical glass requires 2,000 volts pressure to break down a thickness of one-thousandth of an inch, a piece ten one-thousandths of an inch thick requires 20,000 volts pressure to cause breakdown.

7-6. PRACTICAL UNITS

As we know, values of resistance are given in ohms, while values of conductance

are expressed in mhos. However, in radio and television, resistors with values of thousands or even millions of ohms are often found. Radio and television signal voltages picked up by receiving antennas are often measured in millionths of a volt. Currents of a few thousandths of an ampere are often found in radio circuits. Even the frequency of a radio wave is expressed in thousands or millions of cycles per second. So, often in our radio and television service work, we find that ampere, volt, ohm, cycle, and many others are units either too small or too large to use conveniently. For example, conductance is very often expressed in micromhos and very seldom in mhos.

You may recall that, in Theory Lesson 1, we discussed two prefixes used in radio to simplify the expression of high frequencies. They were *kilo*, which stands for one thousand, and *mega*, which stands for one million. For example, the frequency of radio station WRCA is given as 660 kc (kilocycles), while the picture carrier frequency of TV channel 4 is 67.25 mc (megacycles). Table D shows some frequently used electrical units. For instance, note that 1,000 watts is written as 1 kilowatt. Thus, 5,000 watt-hours would appear on your electric bill as 5 kilowatt-hours. In Table D, three new prefixes are introduced: *milli*, which stands for one thousandth (1/1000), *micro*, which stands for one millionth (1/1,000,000), and *micromicro*, which stands for one millionth of one millionth (1/1,000,000,000,000).

7-7. POWERS OF TEN

You will notice that, in the last column of Table D, practical electrical units may also be expressed by using *powers of ten*. Radio servicemen, technicians, and engineers make use of this short way of writing large numbers. Take a number like 6.24 quintillion, which is written like this: 6,240,000,000,000,000,000. (You may remember from Theory Lesson 5 that this is the number of electrons in one coulomb of electricity.) It is a very large number to write or to work with. Sometimes it is easier to express large numbers by using powers of ten. For instance, the number of electrons in a coulomb, in powers of ten, is expressed as 6.24×10^{18}, and is read, "six point two four times ten to the eighteenth power." Calculations in radio are greatly simplified by the use of this shorthand system. The following list shows how it works:

$$1 = 10^0$$
$$10 = 10^1$$
$$100 = 10^2$$
$$1,000 = 10^3$$
$$10,000 = 10^4$$
$$100,000 = 10^5$$
$$1,000,000 = 10^6, \text{ etc.}$$

The power of ten is increased by 1 with each additional zero.

TABLE C - DIELECTRIC STRENGTHS OF SOME INSULATING MATERIALS IN VOLTS PER MIL OF THICKNESS

Insulating Material	*Volts Per Mil of Thickness*
Air (sea level)	19.8 – 22.8
Amber	2,300
Asphalt	25-30
Cellulose-Acetate	250 – 1,000
Cellulose-Nitrate	300-780
Fibre	150-180
Glass, Crown	500
Glass, Electrical	2,000
Glass, Pyrex	335
Mica, Clear, India	600 – 1,500
Micalex 364	350
Nylon	305
Paper	1,250
Paraffin Oil	381
Paraffin Wax	203-305
Phenol-Formaldehyde	400-475
Phenol-Yellow	500
Porcelain, Wet Process	150
Porcelain, Dry Process	40-100
Quartz, Fused	200
Rubber, Hard	450
Shellac	900
Steatite, Low-Loss	150-315
Varnished Cloth	450-550
Vinyl Resins	400-500

TABLE D – PRACTICAL ELECTRICAL UNITS

Unit	Abbreviation	Equivalent			Powers of Ten
milliampere	ma	$\frac{1}{1,000}$ a	or	0.001 a	10^{-3} ampere
microampere	µa	$\frac{1}{1,000,000}$ a	or	0.000,001 a	10^{-6} ampere
micromicro-ampere	µµa	$\frac{1}{1,000,000,000,000}$ a	or	0.000,000,000,001 a	10^{-12} ampere
kilovolt	KV	1,000 v			10^{3} volts
millivolt	mv	$\frac{1}{1,000}$ v	or	0.001 v	10^{-3} volt
microvolt	µv	$\frac{1}{1,000,000}$ v	or	0.000,001 v	10^{-6} volt
micromicro-volt	µµv	$\frac{1}{1,000,000,000,000}$ v	or	0.000,000,000,001 v	10^{-12} volt
kilohm	kΩ	1,000 ohms			10^{3} ohms
megohm	M	1,000,000 ohms			10^{6} ohms
millimho		$\frac{1}{1,000}$ mho	or	0.001 mho	10^{-3} mho
micromho	µmho	$\frac{1}{1,000,000}$ mho	or	0.000,001 mho	10^{-6} mho
kilowatt	KW	1,000 w			10^{3} watts
milliwatt	mw	$\frac{1}{1,000}$ w	or	0.001 w	10^{-3} watt
microwatt	µw	$\frac{1}{1,000,000}$ w	or	0.000,001 w	10^{-6} watt

$$0.1 = 10^{-1}$$
$$0.01 = 10^{-2}$$
$$0.001 = 10^{-3}$$
$$0.0001 = 10^{-4}$$
$$0.00001 = 10^{-5}$$
$$0.000001 = 10^{-6}$$

The negative power of ten is increased by 1 with each additional decimal place.

Naturally, it saves time and space to use powers of ten when there are several zeros in a number. It doesn't pay to write numbers like 137,776,241 or 0.6314159 in powers of ten. However, a number like 300,000,000 is simpler when written as 3×10^8, and 0.000000000022 is easier to work with as 2.2×10^{-11} or 22×10^{-12}. When a number is written in this form it always has two parts. The first part has one or more digits (not a zero) on the left of the decimal point, and usually other digits on the right of the decimal point. The other part is a power of 10 which places the decimal point in its true position if the indicated multiplication is carried out. This method of writing numbers often simplifies the calculation and the location of the decimal point.

One of two methods may be used to write numbers in the "powers of ten" form. The first method is based on a fundamental understanding of the system, and should be used until these fundamentals are well understood. Later the second method, which is more suited for rapid computation, may be used.

The first method is as follows:

1. The tables at the bottom of page 8 and the top of page 10 should be memorized.

2. Separate the number into two parts, so that one part is in the form given in the tables. For example, 0.009 can be separated into 9×0.001. But from the table, 0.001 is 10^{-3}. Therefore, $0.009 = 9 \times 10^{-3}$.

3. As another example: $3{,}700 = 3.7 \times 1{,}000 = 3.7 \times 10^3$.

4. As another example: given $8.34 \times 10^4 = 8.34 \times 10{,}000 = 83{,}400$.

The second method is as follows:

1. Place a decimal point at the right o the first non-zero digit. In using this rule the first non-zero digit is to be counted from the left; thus, in 8,749, the digit 8 is the first non-zero digit.

2. Start at this decimal point and *coun the digits and zeros passed over in reaching the original decimal point.* The result of the count is the numerical value of the power o exponent of 10. If the count is toward th right to reach the original decimal point, th exponent is positive (+). If the count is toward the left to reach the original decima point the exponent is negative (-).

Thus, the number in powers of ten i written as the number found in the first ste multiplied by 10 with the exponent found i the second step. For example, if the numbe is 6203.4 a new decimal point is placed afte the six. Then the number of digits and zero passed over to reach the original decima point is found to be three. Thus the numbe in powers of ten form is 6.2034×10^3. Belo are some numbers and their power-of-te equivalents:

$$47290 = 4.729 \times 10^4$$
$$0.000369 = 3.69 \times 10^{-4}$$
$$334{,}000{,}000{,}000 = 3.34 \times 10^{11}$$
$$17{,}000{,}000 = 1.7 \times 10^7$$
$$0.000000000012 = 1.2 \times 10^{-11}$$
$$0.00031 = 3.1 \times 10^{-4}$$

The last two examples may also be wri ten as follows:

$$0.000000000012 = 1.2 \times 10^{-11} = \frac{1.2}{10^{11}}$$

$$0.00031 = 3.1 \times 10^{-4} = \frac{3.1}{10^4}$$

Note: that when a power of ten is broug up (or down) across the fraction line, t sign of the exponent must be changed; negative exponent becomes a positive e ponent, and vice versa.

If a number given in powers of ten is to be written in ordinary form, the numbers should be re-copied. Then, starting at the decimal point the number of places indicated by the exponent should be counted, supplying the necessary zeros and the new decimal point put in. If the exponent is positive, the count is toward the right; if negative, the count is toward the left. This rule may be illustrated by examining the examples above in reverse order.

When we use powers of ten, multiplication and division of large numbers become much easier. The rules are simple:

1. When multiplying, add exponents.
2. When dividing, subtract exponents.

Let us see now how this can be used to simplify the calculation of 5,790,000 x 0.000283. By the procedure of the two steps stated above, this can be written as $5.79 \times 10^6 \times 2.83 \times 10^{-4}$. By combining the exponents of 10, this is written as $5.79 \times 2.83 \times 10^2$. (In multiplication, the exponents are are added; $10^{-4} \times 10^6 = 10^2$.) Then since 5.79 is almost 6, and 2.83 is almost 3, the product of these two numbers is about 18. Actual multiplication shows it to be 16.39. Hence, $5.79 \times 2.83 \times 10^2 = 16.39 \times 10^2 = 1639$. The answer can be left in this form, or written as 1.639×10^3.

For convenience in calculation, the form of the number can be changed as desired. For example, 1.234×10^3 can be written as 12.34×10^2. The rule is: If the first part of the number is increased by 10 (decimal point moved one place to the right), the exponent of 10 is decreased by one. Or if the exponent of 10 is increased by one, the number is decreased by 10 (decimal point moved one place to the left).

Example 1:

$1,234 = 1.234 \times 10^3 = 12.34 \times 10^2$

$= 0.1234 \times 10^4 = 12,340 \times 10^{-1}$

Example 2:

$0.00314 = 3.14 \times 10^{-3} = 31.4 \times 10^{-4}$

$= 0.314 \times 10^{-2}$

Example 3:

$$\frac{36 \times 10^5}{2 \times 10^2} = \frac{360 \times 10^4}{2 \times 10^2} = 180 \times 10^2 = 18 \times 10^3$$

Example 4:

$$\frac{36 \times 10^5}{2 \times 10^{-2}} = \frac{36 \times 10^5 \times 10^2}{2} = 18 \times 10^7$$

Example 5:

$12,000 \times 11,000,000$

$12,000 = 1.2 \times 10^4$

$11,000,000 = 1.1 \times 10^7$

$1.2 \times 10^4 \quad \times 1.1 \times 10^7$

$= 1.2 \times 1.1 \times 10^{4+7}$

$= 1.32 \times 10^{11}$

$= 132,000,000,000$

Example 6:

0.0003×0.000009

$0.0003 = 3 \times 10^{-4}$

$0.000009 = 9 \times 10^{-6}$

$3 \times 10^{-4} \times 9 \times 10^{-6}$

$= 3 \times 9 \times 10^{(-4)+(-6)}$

$= 27 \times 10^{-10}$

$= 0.0000000027$

Example 7:

$700,000 \times 0.0004$

$700,000 = 7 \times 10^5$

$0.0004 = 4 \times 10^{-4}$

$7 \times 10^5 \times 4 \times 10^{-4}$

$= 7 \times 4 \times 10^{5-4}$

$= 28 \times 10^1$

$= 28 \times 10 = 280$

Note that when we add plus 5 and minus 4, we get plus 1.

When dividing with powers of ten, sub-

tract the exponent of the divisor from the exponent of the dividend (the amount to be divided). For example:

Example 8:

$360{,}000 \div 40$

$360{,}000 = 3.6 \times 10^5$

$= 36 \times 10^4$

$40 = 4 \times 10^1$

$36 \times 10^4 \div 4 \times 10^1$

$= (36 \div 4) \times 10^{4-1}$

$= 9 \times 10^3$

$= 9{,}000$

Note that we used 36×10^4 instead of 3.6×10^5 to make the final division easier.

Example 9:

$220{,}000 \times 45{,}000 \times 3{,}000$

$= 2.2 \times 10^5 \times 4.5 \times 10^4 \times 3 \times 10^3$

$= 2.2 \times 4.5 \times 3 \times 10^5 \times 10^4 \times 10^3$

$= 29.7 \times 10^{12}$

Example 10:

$500{,}000 \times 0.00006 \times 0.002 \times 40{,}000$

$= 5 \times 10^5 \times 6 \times 10^{-5} \times 2 \times 10^{-3} \times 4 \times 10^4$

$= 5 \times 6 \times 2 \times 4 \times 10^5 \times 10^{-5} \times 10^{-3} \times 10^4$

$= 240 \times 10^1 = 2400$

Example 11:

$$\frac{12{,}000 \times 8{,}000 \times 0.005}{40{,}000}$$

$$= \frac{1.2 \times 10^4 \times 8 \times 10^3 \times 5 \times 10^{-3}}{4 \times 10^4}$$

$$= \frac{48 \times 10^4}{4 \times 10^4} = \frac{48}{4} = 12$$

Example 12:

$0.0012 \times 5{,}000 \times 0.00004 \div 0.02 \times 0.04 \times 5$

$= 12 \times 10^{-4} \times 5 \times 10^3 \times 4 \times 10^{-5} \div 2 \times 10$

$\times 4 \times 10^{-2} \times 5 \times 10^2$

$= 12 \times 5 \times 4 \times 10^{-4} \times 10^3 \times 10^{-5}$

$\div 2 \times 4 \times 5 \times 10^{-2} \times 10^{-2} \times$

$= 240 \times 10^{-6} \div 40 \times 10^{-2}$

$$= \frac{240 \times 10^{-6}}{40 \times 10^{-2}} = \frac{240 \times 10^{-6}}{40 \times 10^{-2}}$$

$= 6 \times 10^{-4} = 0.0006$

Example 13:

$4{,}180{,}000 \times 50{,}000 \times 0.005 \div 0.0055$

$= 4.18 \times 10^6 \times 5 \times 10^4 \times 5 \times 10^{-3} \div 55 \times 10$

$= 4.18 \times 5 \times 5 \times 10^6 \times 10^4 \times 10^{-3} \div 55 \times 10$

$= 104.5 \times 10^7 \div 55 \times 10^{-4}$

$$= \frac{104.5 \times 10^7}{55 \times 10^{-4}}$$

$$= \frac{104.5 \times 10^7 \times 10^4}{55} = \frac{104.5}{55} \times 10^{11}$$

$= 1.9 \times 10^{11}$

The examples you have just seen sh you how to work with powers of ten. Ho ever in order to be completely prepared solve problems that use powers of ten, y should practice solving such problems ur you have no trouble with them. Make up y own problems and solve them. Check y results by using ordinary arithmetic with powers of ten.

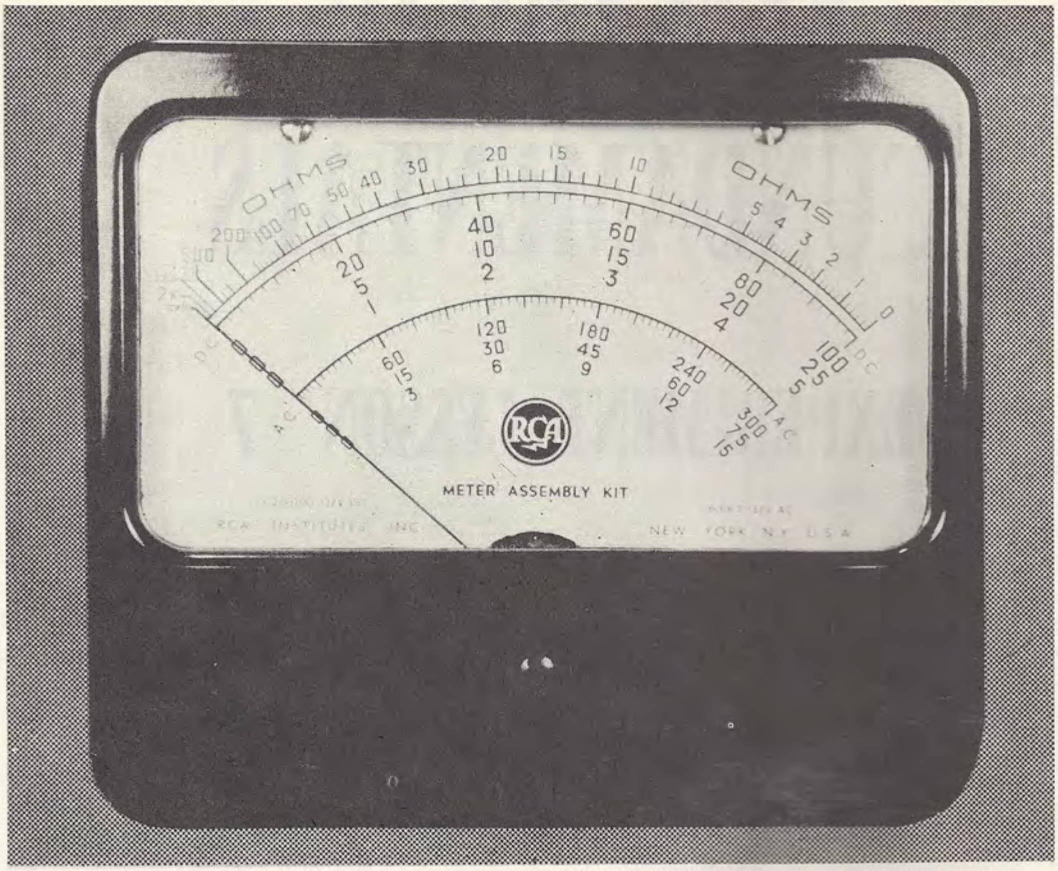
As you practice solving such probler you will find that it becomes easier a easier to use powers of ten. Soon you w be using powers of ten more easily than y now use the arithmetic you already kn

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 7

METER ASSEMBLY AND MEASUREMENT OF D.C.

RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.



All the parts in Kit 4 are listed below. Check the parts you receive against this list. Make sure you have the correct quantity of every item. If a part is either missing or defective upon arrival. request a replacement from Department R, Home Study School, RCA Institutes, Inc., 350 West 4th Street, New York 14, N.Y. *Your request must include your name and student number, the complete name and description of the part copied from the Item column below, the Quantity missing or defective, and the reason you are asking for a new part.*

KIT 4
BILL OF MATERIALS

Quantity	Item	Quantity	Item
1	50-μa meter	4	#6 lock washers
4	#6 nuts	2	1/4" brass flat washers
2	1/4" solder lugs, locking type	4	Brass nuts

The fine wire attached to both terminals of your 50-μa meter movement serves to dampen needle movement during shipment. Remove this wire before performing any experiments and attaching your meter movement to the multimeter assembly. If you ship a movement that has been removed from a multimeter, attach a similar piece of wire across both terminals. If you ship a complete multimeter, it is not necessary to use this wire if you set the FUNCTION switch to DC and the RANGE switch to the 1A position. A meter movement is like a fine watch. It should *not* be opened and serviced by someone who is not an experienced instrument repairman. Opening or tampering with the movement voids the warranty.

If you should experience difficulty with your meter movement or multimeter assembly, write for information and instructions. *Do not return either of these items without writing first.*

Experiment Lesson 7

OBJECT

1. To complete the wiring of the d-c section of the multimeter.

2. To use the multimeter to measure direct current and voltage.

PREPARATION

Before performing any of the experiments in this lesson, carefully read the instructions given in Service Practices 7, How to Use and Read a Meter. After spending so much time and care in preparing your multimeter, it would be downright silly to risk using it without knowing how to use it properly and how to care for it.

PART ONE

EQUIPMENT NEEDED

Kit 4

Soldering iron

Cloth for keeping soldering tip clean

Solder

Long-nose pliers

Cutting pliers

Adjustable crescent wrench, or 1/4" and 3/8" open-end or box wrenches

Fine-blade screwdriver

UNPACKING KIT

Caution: Handle this kit with care. It contains your meter movement, which is as fine and delicate as a watch movement. Don't drop it or do anything to it that you would not do to a fine watch. Learn to care for your meter and it will help you in your work and help you make money; be careless with your meter and you will lose time in your work and spend money for repairs.

Unpack Kit 4 and check the contents against the Bill of Materials. Then, remove the fine wire wrapped around the terminals of the meter. Place the meter and hardware aside for a while.

PREPARATION

1. Examine carefully the work done up to now on your multimeter. See that each resistor and part is placed where it should be and that each is properly wired.

2. Clear the table or bench where you work and arrange your tools for easy use.

3. See that your soldering iron is clean and ready for use.

4. Examine Fig. 7-1 and 7-2 to see the assembling and wiring to be done in this part of the lesson.

JOB 7-1

To mount meter movement, as shown in Fig. 7-3.

Procedure.

Step 1. Place the four brass meter-mounting screws through the four holes in the panel and the meter through the large

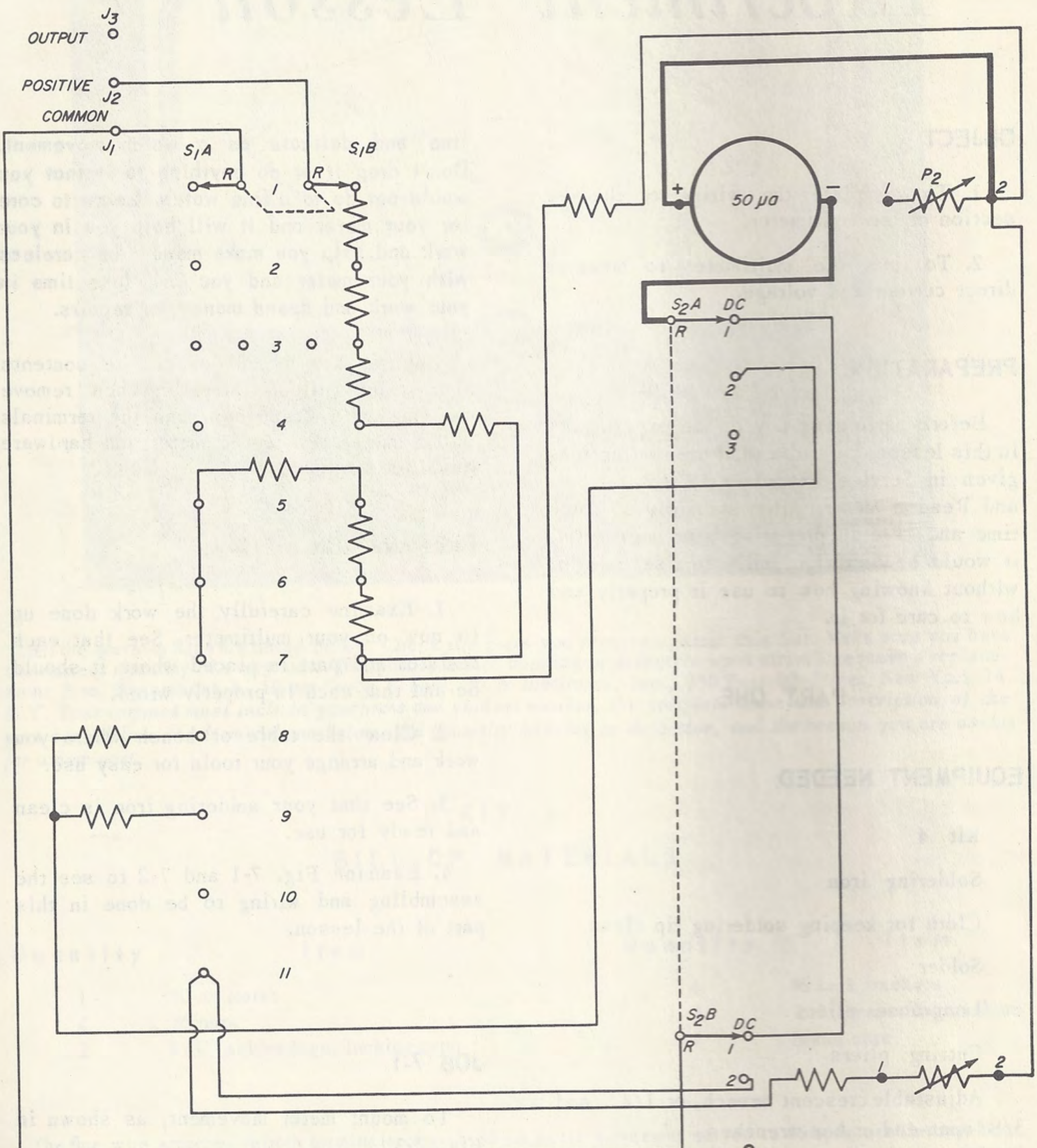


Fig. 7-1 Meter Connections to be Made in This Lesson

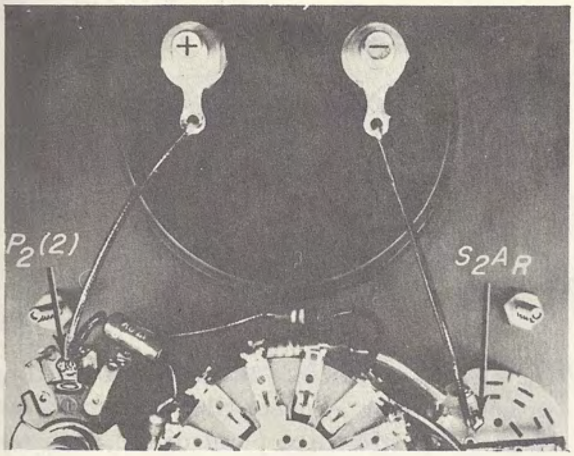


Fig. 7-2

center hole so that the top of the meter faces the top of the panel.

Step 2. Fasten the meter in place by tightening with one small lockwasher and one 6-32 nut on each meter screw.

Caution: Be very careful in tightening the meter nuts. If you use too much force, you may crack the bakelite case of the meter movement or loosen the screws from the meter.

Step 3. Make sure that the large meter lugs are clean; then mount them on the meter terminal screws. Place each lug with the tabs facing in the direction shown in Fig. 7-4*a*. Place a brass washer and a large meter nut on top of each lug.

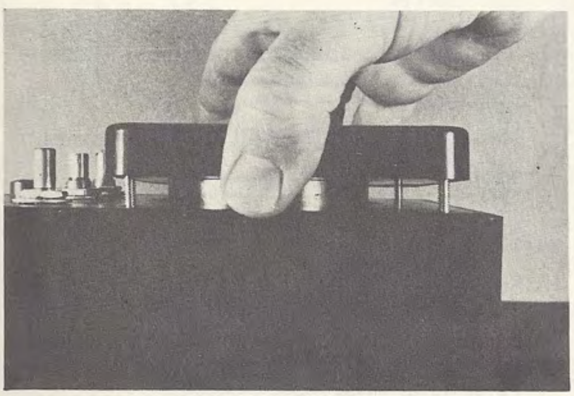
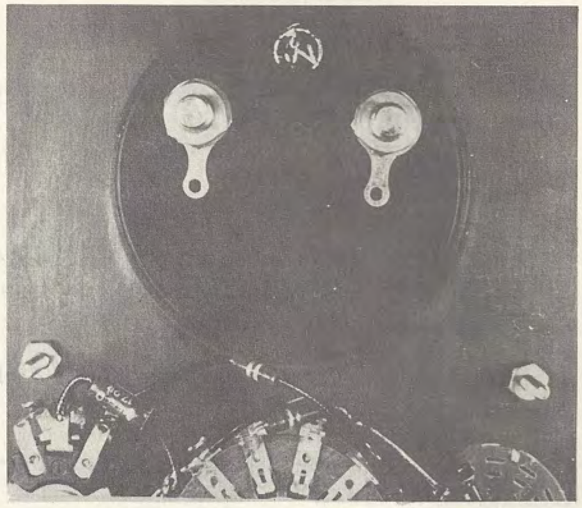
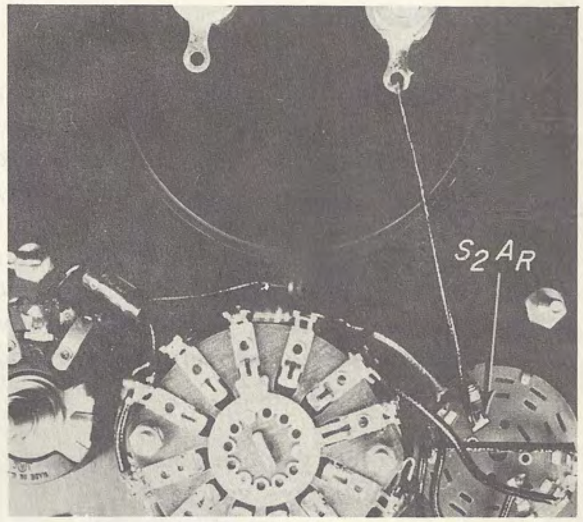


Fig. 7-3



(a)



(b)

Fig. 7-4

JOB 7-2

To connect the rotor of switch S_2A to the negative meter terminal.

Procedure.

Step 1. Cut a 3-inch length of solid hook-up wire. Strip 1/4 inch of insulation from each end.

Step 2. Solder one end to S_2A_R.

Step 3. Dress the wire neatly, as shown in Fig. 7-4*b*, and solder the other end to the negative meter terminal.

JOB 7-3

To connect terminal 2 of potentiometer P_2 to the positive meter terminal.

Procedure.

Step 1. Cut a 3-inch length of solid hook-up wire. Strip 1/4 inch of insulation from each end.

Step 2. Solder one end to terminal 2 of potentiometer P_2.

Step 3. Solder the other end to the positive meter terminal.

CHECK YOUR WORK

With the connection made in Step 3, your multimeter is wired to measure d-c voltage and current. Later on you will complete the ohmmeter sections. When you study alternating current, you will receive additional parts, which you will add to your multimeter so that it will also measure a-c voltage. In the meantime, you will learn how to use your meter to measure voltage and currents in d-c circuits.

However, before you use your multimeter, there are several things you must do.

1. Check your wiring and placement of parts.

2. See that all the connections you have made are soldered (except S_2A_2).

3. Examine the RANGE switch, S_1, for bits of wire or solder that may have dropped down between the contacts.

4. When you are sure that everything is in its proper place, turn the meter panel right side up and insert the meter in the case. Fasten the meter panel at the four corners with the four small panel screws. Tighten the screws carefully so that you do not cause too much strain on the panel corners.

ADJUST KNOBS

Turn the FUNCTION switch (AC-OHMS-DC) knob clockwise as far as it will go without forcing. Loosen the set screw and line up the arrow-like point of the knob with the DC marker line, as shown in Fig. 7-5. Retighten the set screw.

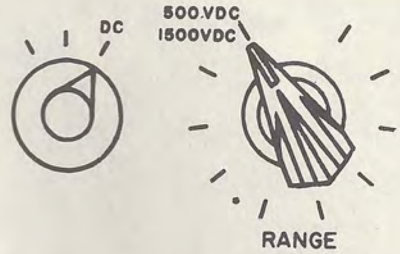


Fig. 7-5

Turn the RANGE switch clockwise as far as it will go without forcing. Loosen the set screw and line up the pointer knob with the 500-VDC marker line. Retighten the set screw. The knob should now indicate each range position correctly. To check this, turn the knob counterclockwise as far as it will go. It should come to rest on the R x10K position. Turn the knob to the 500 VDC position and leave it there.

Caution: Before attempting to use your multimeter, be sure to read carefully the instructions given in Service Practices 7, *How To Read Meters.*

PART TWO

EQUIPMENT NEEDED

Multimeter

Test prods made in Experiment Lesson 2

Resistor board wired in Experiment Lesson 1

Soldering iron

Solder

Cloth for keeping soldering tip clean

Long-nose pliers

Three 1.5-volt cells from Kit 3

Two alligator clips from Kit 1

EXPERIMENT 7-1

To test the multimeter for a voltage reading on the 5 VDC scale with a 1.5-volt dry cell.

Procedure.

Step 1. Turn the FUNCTION switch to the DC marker line.

Step 2. Turn the RANGE switch to the 5 VDC marker line.

Step 3. Place the phone tip of the black test lead in the black COMMON pin jack and the tip of the red test lead in the red(+, meaning positive) pin jack. If you have performed these three steps correctly, your multimeter and test leads will look like the meter shown in Fig. 7-6.

Step 4. Press the point of the black test prod firmly against the negative zinc electrode of one of the 1.5-volt dry cells. Press the point of the red test prod against the positive brass electrode of the dry cell, as shown in Fig. 7-7*a*. The meter needle should be in about the position shown in Fig. 7-7*b*.

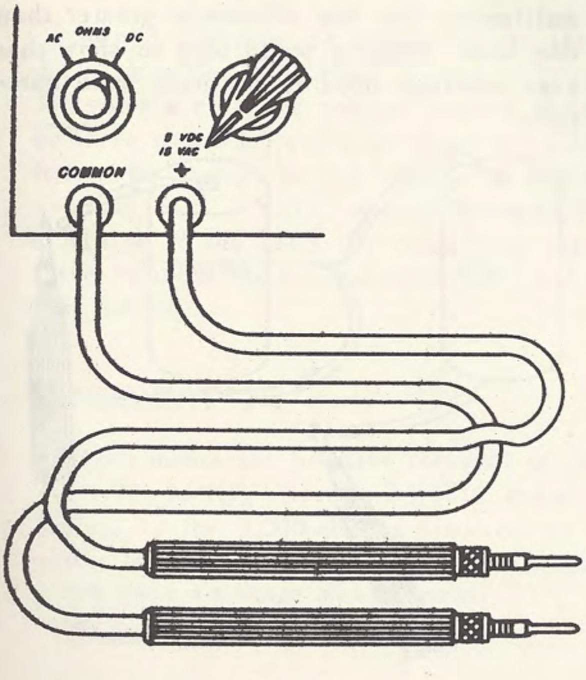
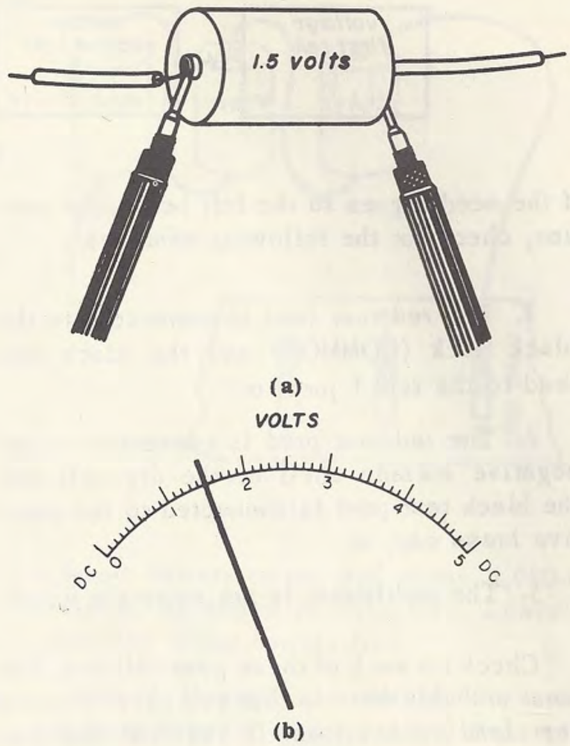
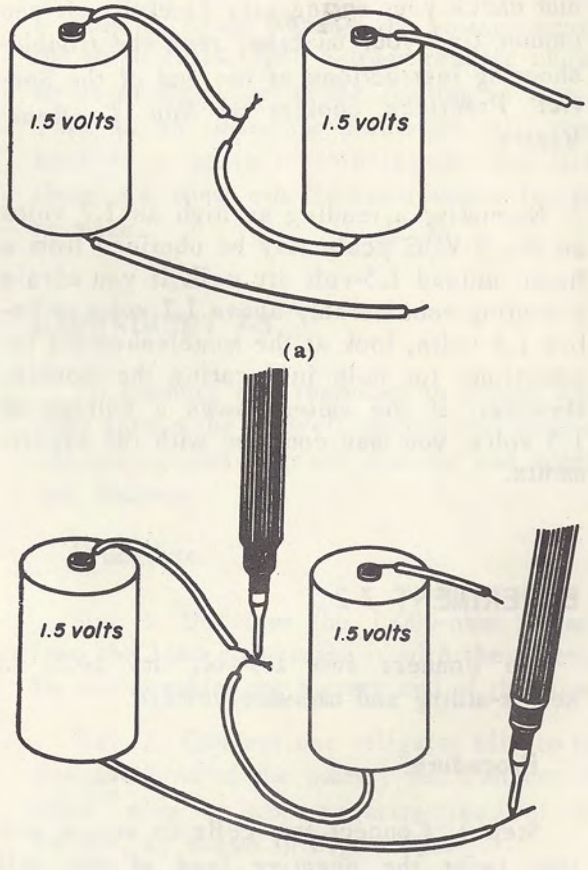


Fig. 7-6



(b)

Fig. 7-7



(b)

Fig. 7-8

voltage first cell		voltage second cell		total figured		total measured
1.5 v	+	1.5 v	=	3.0 v	=	3.0 v

Fig. 7-9

If the needle goes to the left below the zero line, check for the following mistakes:

1. The red test lead is connected to the black jack (COMMON) and the black test lead to the red + jack, or

2. The red test prod is connected to the negative outside shell of the dry cell and the black test prod is connected to the positive brass cap, or

3. The multimeter is not correctly wired.

Check for each of these possibilities. The most probable error is that you have reversed test lead connections. If you find that you haven't made one of the first two errors, remove the meter assembly from the meter box and check your wiring very carefully. If you cannot find your mistake, read the troubleshooting instructions at the end of the Service Practices booklet on *How To Read Meters.*

Normally, a reading as high as 1.7 volts on the 5 VDC scale may be obtained from a fresh, unload 1.5-volt dry cell. If you obtain a reading considerably above 1.7 volts or below 1.5 volts, look at the troubleshooting instructions for help in locating the trouble. However, if the meter shows a voltage of 1.5 volts, you may continue with the experiments.

EXPERIMENT 7-2

To connect two 1.5-volt dry cells in series-aiding and measure voltage.

Procedure.

Step 1. Connect two cells in series aiding; twist the negative lead of one cell together with the positive lead of another cell, as shown in Fig. 7-8*a*.

Step 2. Measure the voltage of the first cell, as shown in Fig. 7-8*b*. It should be about 1.5-volts. Read the meter carefully and record your reading in the first box of Fig. 7-9.

Step 3. Measure the voltage of the second cell. Read this voltage carefully and record it in the second box of Fig. 7-9.

Step 4. Add these two readings and write the total in the third box of Fig. 7-9.

Step 5. Measure the voltage of the two cells in series as shown in Fig. 7-10. Read the meter carefully and record this voltage in the fourth box of Fig. 7-9. By connecting these two cells in series aiding, you have made a 3-volt battery.

If you have read the meter carefully and added accurately, the voltage in the third box should equal the voltage reading in the fourth box. Of course, the reading may vary as much as one scale division and still be within the accuracy rating of the assembled multimeter. But any difference greater than one scale division would tend to show that your readings need to be made more carefully.

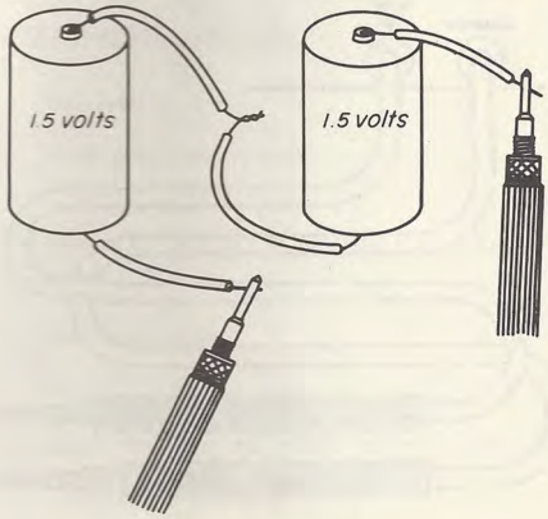


Fig. 7-10

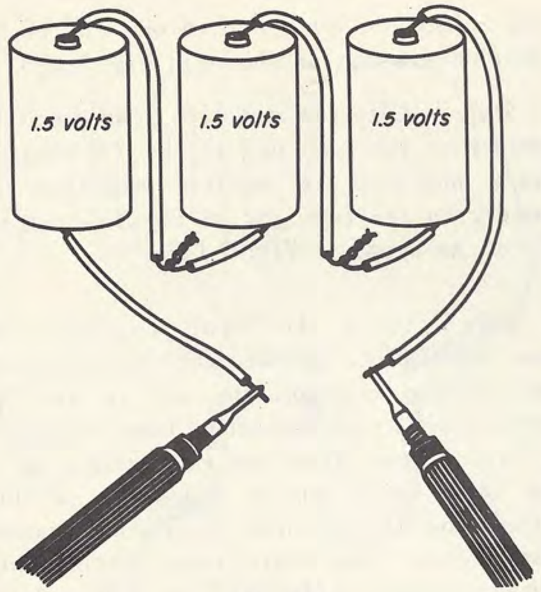


Fig. 7-11

EXPERIMENT 7-3

To connect three 1.5-volt dry cells in series aiding and make a voltage measurement.

Procedure.

Step 1. Connect the remaining 1.5-volt cell in series aiding with the two cells already connected together, as shown in Fig. 7-11.

Step 2. Measure the voltage of the three cells in series, as shown in Fig. 7-11. At 1.5 volts a cell, the voltage reading should be three times 1.5 volts, or about 4.5 volts. It may be as high as 5.1 volts, or it may be as low as 4.2 volts, depending upon the condition of the cells. By connecting these three cells in series, you have made a 4.5-volt battery.

EXPERIMENT 7-4

To connect the positive terminal of your 4.5-volt battery (three 1.5-volt cells in series) to the 1,000-ohm resistor of the resistor board you made in Experiment Lesson 1 and make a voltage measurement.

Procedure.

Step 1. Solder the positive lead of the

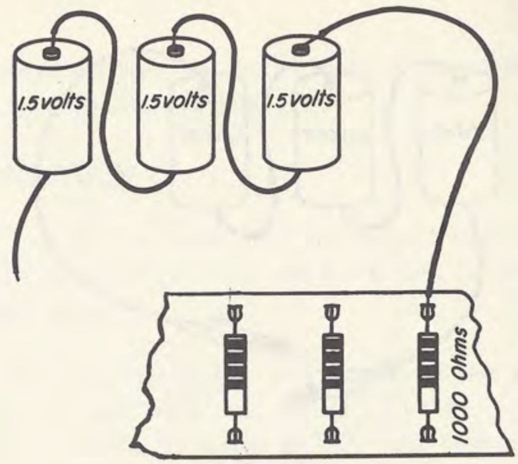


Fig. 7-12

4.5-volt battery to one end of the 1,000-ohm resistor, as shown in Fig. 7-12. Leave the other end of the battery free.

Step 2. Measure the voltage between the negative terminal of the 4.5-volt battery and the free end of the thousand-ohm resistor. Record the voltage here 4.55

Step 3. Again measure the voltage across the three cells. This voltage reading should be about the same as the reading in Step 2. This is an important point. We will come back to it again in this lesson. But first, there are some other measurements for you to make. 4.6

EXPERIMENT 7-5

To connect two resistors in series as a load across the 4.5-volt battery and measure the voltage across each resistor and across the battery.

Procedure.

Step 1. Unsolder the 1,000-ohm resistor from the lead connecting it with the battery. Do not unsolder the battery end of this lead.

Step 2. Connect one alligator clip to the positive lead of the battery and connect the other clip to the negative lead of the battery, as shown in Fig. 7-13*a*.

Step 3. Cut a 2-inch length of bare tinned wire. Solder one end to the 220-ohm resistor

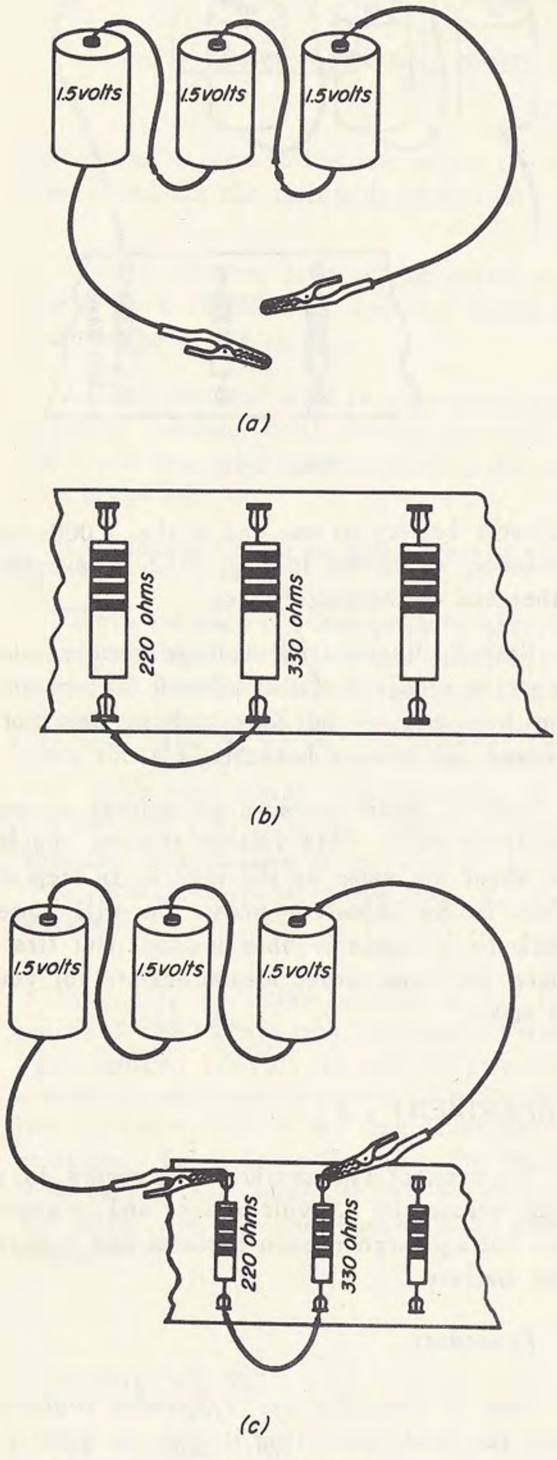


Fig. 7-13

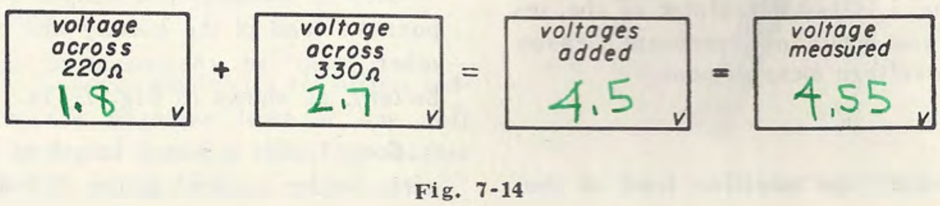


Fig. 7-14

and solder the other end to one end of the 330-ohm resistor, as shown in Fig. 7-13*b*.

Step 4. Clip the negative lead from the battery to the free end of the 220-ohm resistor and clip the positive lead from the battery to the free end of the 330-ohm resistor, as shown in Fig. 7-13*c*.

Step 5. Using the 5-volt d-c range on your multimeter, measure the voltage across the 220-ohm resistor. Be sure to use the correct polarity in connecting your test prods to this resistor. If, in this measurement or in any other measurement you make in this lesson, you find the meter reading backwards, just reverse your test prods. Record this voltage reading in the first box of Fig. 7-14.

Step 6. Measure the voltage across the 330-ohm resistor. Record this voltage in the second box of Fig. 7-14.

Step 7. Add the two voltage readings and record the amount in the third box of Fig. 7-14.

Step 8. Measure the voltage at the positive and negative terminals of the battery. Record this reading in the fourth box of Fig. 7-14. Disconnect the battery from the resistors. You do this so as not to waste battery energy. If your measurements are correct, the voltage shown in box 3 should equal the voltage shown in box 4.

EXPERIMENT 7-6

To connect three resistors in series and place them as a load across the 4.5-volt battery, and to measure the voltages.

Procedure.

Step 1. Cut a 2-inch length of bare tinned wire. Solder one end to the free end

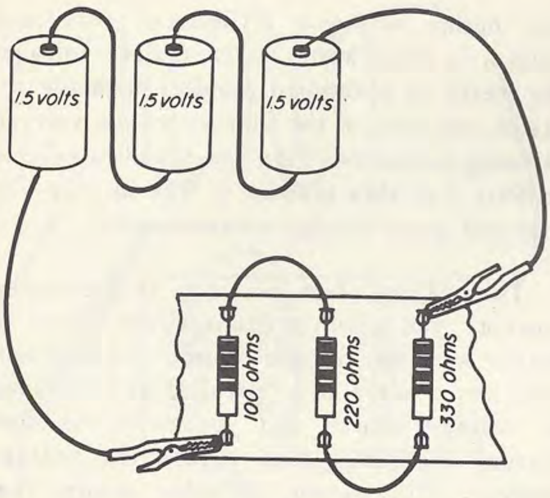


Fig. 7-15

of the 220-ohm resistor. Solder the other end of the wire to one end of the 100-ohm resistor.

Step 2. Clip the negative lead of the 4.5-volt battery to the free end of the 100-ohm resistor. Clip the positive terminal to the free end of the 330-ohm resistor, as shown in Fig. 7-15.

Step 3. Measure the voltage across the 100-ohm resistor. Record this reading in the first box of Fig. 7-16.

Step 4. Measure the voltage across the 220-ohm resistor and record it in the second box of Fig. 7-16.

Step 5. Measure the voltage across the 330-ohm resistor and record it in the third box.

Step 6. Add the three voltages readings and write the amount in the fourth box.

Step 7. Measure the voltage across the terminals of the battery and record the amount in the fifth box. Disconnect the battery from the circuit by unclipping the battery leads from the resistor board. The voltage written in box 4 should equal the voltage reading in box 5.

DISCUSSION

Let us see what may be learned from the voltage measurements you have just made in Part Two.

In Experiment 7-1, you measured the voltage of one cell and found it to be about 1.5-volts. In Experiment 7-2, you measured the voltage of two cells in series and you found this voltage to be about 3 volts. In Experiment 7-3, you measured the voltage of three cells in series and you found it to be about 4.5-volts. From your own measurements, therefore, you found that the theory you studied in Theory Lesson 5 is true; the voltage of one cell adds to the voltage of another cell when they are connected in series aiding – that is, when the positive terminal of one cell is connected to the negative terminal of the next cell.

We will skip Experiment 7-4 for a moment, and go on to Experiment 7-5, in which you placed two resistors in series as a load across the battery and found that the applied voltage (from the battery) divided into two parts. The greater voltage was across the resistor with the greater resistance. You found that the sum of the voltage drops across the resistors was equal to the applied voltage. In Experiment 7-6, when you connected three resistors in series, you found that the applied voltage divided into three parts, that the smallest voltage drop was across the resistor with the least resistance, and that the greatest voltage drop was across the resistor with the most resistance. Again, you found that the sum of the voltage drops was equal to the applied voltage. This important fact is discussed completely in Theory Lesson 8.

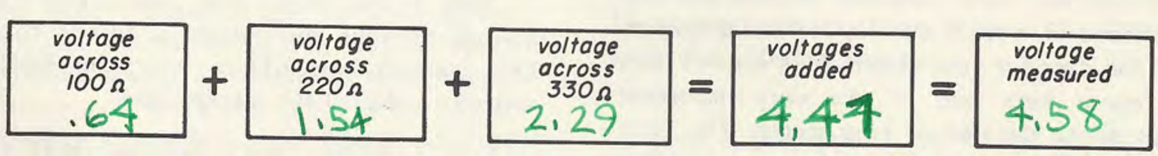


Fig. 7-16

Now, let us examine what you found in Experiment 7-4. You found that there was no voltage drop across the 1,000-ohm resistor. Yet, in later steps, you found noticeable voltage drops across even resistors of much less resistance. It seems puzzling at first, but the reason is not hard to understand. You could measure no voltage drop across the 1,000-ohm resistor because you were measuring voltage in an open circuit. It was an open circuit because only one terminal of the battery was connected to the resistor. The other terminal of the battery and the other end of the resistor were free. When a circuit is open, there is no current flow. According to Ohm's Law, which you studied in Lesson 5, *voltage* is equal to *current* times *resistance* $(E = IR)$. If there is no current, there can be no voltage drop. If the circuit has been completed (if the free end of the 1000-ohm resistor has been connected to the other terminal of the battery) there would have been a voltage drop across the resistor.

Actually, when the meter was connected to the free end of the resistor and the free end of the battery, the circuit was completed by the meter; but the amount of current flowing through the meter was so small that there was practically no difference between the readings at either end of the resistor. For that reason, we can ignore this meter current. The fact that there is no voltage drop across the resistor in an open circuit is one of the tests that a serviceman uses in locating open circuits in a radio receiver. For that reason, it is discussed here.

PART THREE

INFORMATION

While you have probably studied Service Practices 7 very carefully to learn how to use and care for your meter, it is a good idea to repeat here one or two very important facts about the use of your meter. The first of these is that voltage is measured by placing the test prods of the meter at any two points where a difference in voltage exists. In other words, in measuring voltage, the meter is placed in parallel with the resistor, the cell or the battery whose voltage is being measured. This you found to be true in Part 2 of this lesson. It was in this way that you made voltage measurements.

The second fact is that in measuring current, you always connect the meter in series with the voltage source and the load. You never place it in parallel with the load or voltage source and you never measure current without a load across the voltage source. This means, in other words, that you never try to measure current by placing an ammeter or milliameter across a battery, a cell, or any other source of electrical power. Nothing that you may ever be told about the use of a meter can be more important than this. There is no easier way to burn out a meter movement than to be careless when measuring current.

EQUIPMENT NEEDED

The same equipment used in Part Two

EXPERIMENT 7-7

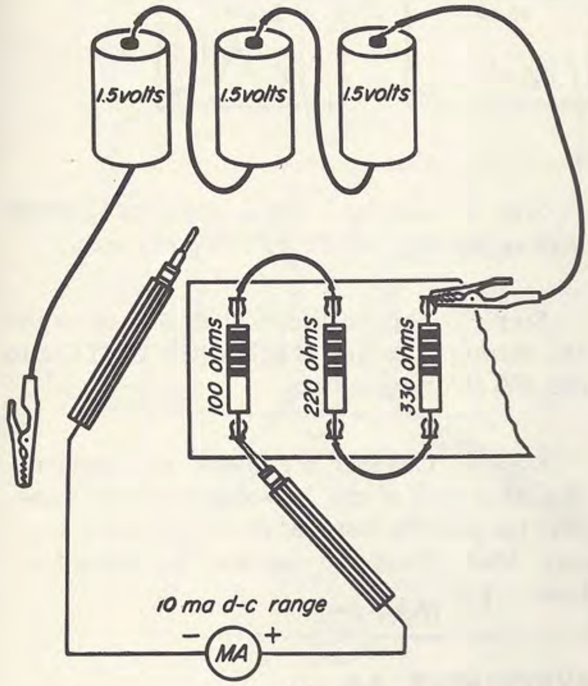
To measure the current flowing in the circuit wired in Experiment 7-6 of Part 2. This circuit consists of three resistors and a battery. Current is measured at several points in the circuit.

Procedure.

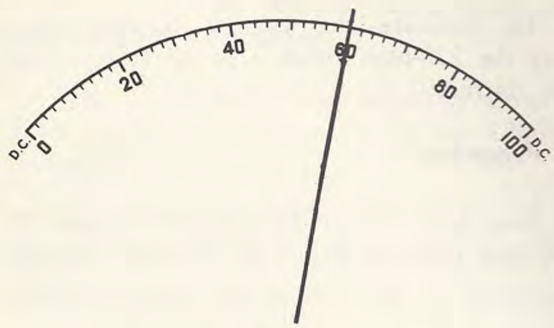
Step 1. The 100-ohm resistor, the 220-ohm resistor, and the 330-ohm resistor should still be connected in series from the last experiment. Clip the positive lead from the battery to the free end of the 330-ohm resistor.

Step 2. Be sure that the FUNCTION switch of your multimeter is turned to the DC marker line. Then turn the RANGE switch to the 10 MA marker line.

Step 3. Place the positive (red) test prod firmly against the free end of the 100-



(a)



(b)

Fig. 7-17

ohm resistor, as shown in Fig. 7-17*a*. Then, as you watch the meter needle, make a rapid brushing stroke with the point of the negative (black) test prod across the lead from the negative terminal of the battery. This brushing stroke is made so that you make and break connection with the battery in one stroke. If, while you make this momentary connection, the meter moves rapidly to the right of the scale, remove both test prods from the circuit. Normally, the meter pointer should come to rest near the 60-ma calibration, as shown in Fig. 7-17*b*. Since the RANGE switch is on the 10 MA position and since you are using the 100-ma scale, the reading you obtain should be divided by 10. Thus, a current of approximately 6 ma is flowing through the circuit.

If you obtain a reading that is not near 6 ma, a mistake may have been made in the connections of the circuit or a mistake has been made in wiring the current ranges of the meter. If the circuit connections are exactly as shown in Fig. 7-17*a*, then remove the meter assembly from the meter box and check the wiring and placement of resistors in Experiment Lesson 5. If you can find no error, turn to the troubleshooting instructions in Service Practices 8 for help in locating the trouble.

If the meter falls below zero when you make the first brushing stroke with your test prod, you will find that either the battery is connected with the wrong polarity or the test prods are not connected correctly. When you have located the trouble, connect the positive test prod to the free end of the 100-ohm resistor and, with the negative test prod, lightly brush the negative battery lead as before.

If the meter rises slowly, as it should, make a firm connection with the negative lead from the battery so that you may make a careful reading. Record this current reading in the first box of Fig. 7-18.

Step 4. Open the circuit between the 100-ohm and 220-ohm resistors by unsoldering one end of the wire that connects them. Clip the negative lead from the battery to the free end of the 100-ohm resistor. The positive clip from the battery should already be connected to the free end of the 330-ohm resistor. As shown in Fig. 7-19, the circuit is now open between the 100-ohm and 220-ohm resistors.

Step 5. Connect the positive test prod to the free end of the 220-ohm resistor and the negative test prod to the free end of the 100-ohm resistor. Read the current and record it in the second box of Fig. 7-18. Disconnect the negative lead of the battery from the 100-ohm resistor.

Step 6. Resolder the lead from the 220-ohm resistor to the free end of the 100-ohm resistor. Unsolder one end of the

that, in each case, the meter is in series with the voltage source and the load resistors. All of these readings were the same. So, in this experiment, you verified a law that is discussed completely in Theory Lesson 8. This law states:

In a series circuit, the same current flows in each part of the circuit.

In Experiment 7-7, you connected the 100-ohm, 220-ohm, and 330-ohm resistors in series with meter that has a resistance of 100 ohms on the 10 MA RANGE. The total resistance of the circuit is thus 750 ohms. The total voltage is approximately 4.5 volts. Using Ohm's Law, the calculated value of current is 6 ma. Look back at your results to see if you obtained approximately 6 ma.

In Experiment 7-8, you connected a 330-ohm resistor in series with the resistance of the meter, which at the 100 MA RANGE is 10 ohms. The total resistance is thus 340 ohms. The voltage of the source is 4.5 volts. The calculated value of current is approximately 13.2 ma.

In Experiment 7-9, the 220-ohm resistor was connected in series with the resistance of the meter (10 ohms), and the series combination connected across approximately 4.5 volts. The calculated current is about 19.5 ma.

In general, you see, with the same applied voltage, the greater the load resistance is, the lower the current; and the lower the load resistance, the higher is the current.

1.5V Battery –

Open Circuit Voltage – 1.4 V

Closed Circuit (Dead short) Voltage – .15 V

*" " 100 Ω load — 1.4 V

1000 Ω load — 1.4 V

100,000 Ω load — 1.4 V

ELECTRONIC FUNDAMENTALS

THEORY LESSON 8

D-C CIRCUITS

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

350 West 4th Street, New York 14, N. Y.

Theory Lesson 8

INTRODUCTION

This lesson is one of the most important and most difficult lessons you will study in this course. Do not rush; take time enough to study it carefully. As suggested in the Introduction to this course, it would be a good idea to read through the entire lesson rapidly, just to get an idea of what it's all about. Then return to the beginning and study each paragraph carefully; make sure that you understand what is said before you go on to the next paragraph. It may be necessary to read through a paragraph several times and to examine the illustrations just as many times before you can be sure that you are ready to go ahead. Just remember that this is a tough one – so take it easy.

8-1. SIMPLE CIRCUITS

From the lessons already studied, we know that for electricity to flow, there must be a conducting path. Only then can electrons move from atom to atom to produce electric current. We know that this path must be continuous (unbroken). We call such a path a *circuit*. If the conducting path is broken at any point, the flow of current stops. For example, in Fig. 8-1*a*, we see a battery, a switch, and a lamp connected together. Current cannot flow because the switch is open. We call this an *open circuit*. However, in Fig. 8-1*b*, which shows the switch closed, current flows; the lamp lights because the circuit is complete. We call this a *closed circuit*.

If a wire is connected from one side of of the battery to the other, as shown in Fig. 8-1*c*, no current flows through the lamp even when the switch is closed. Instead, the current flows only through the battery and the shorting wire. We call this a *short circuit*. When a good conducting path, such as the shorting wire, produces a short circuit, it offers a very heavy load to the battery. The battery soon becomes polarized and unable to produce any useful voltage. Because of the high current that flows, excessive heat is developed, and a fire may result.

If an electric power line is shorted, the generator, which is the source of the power must be protected from the effects of a short circuit. It is protected by fuses or other devices that open the circuit when the current exceeds a safe level. Even battery circuits sometimes have fuses, as shown in Fig. 8-1*d*. When the current reaches a certain level, the metal link in the fuse melts, and the circuit becomes open as shown in Fig. 8-1*e*.

8-2. SERIES CIRCUITS

In electrical circuits, it is often necessary to connect two, three, or more resistors or other electrical units together. When these circuit parts are connected end to end, so that there is only one conducting path in which current may flow, we call it a *series circuit*. For example, in Fig. 8-2*a*, we find a resistor and a lamp connected in series across a battery to form a series circuit. The current flowing from the battery, through the lamp, through the resistor, and back to the battery, is the same. If we measure the current in any part of a series circuit, we find that the same current flows. For example, in the series circuit shown in Fig. 8-2*b*, the current flowing through the three resistors is the same. Therefore,

$$\boxed{I_{R1} = I_{R2} = I_{R3}}$$

From this we may form a rule for series circuits: *In a series circuit, the same current flows in each part of the circuit.*

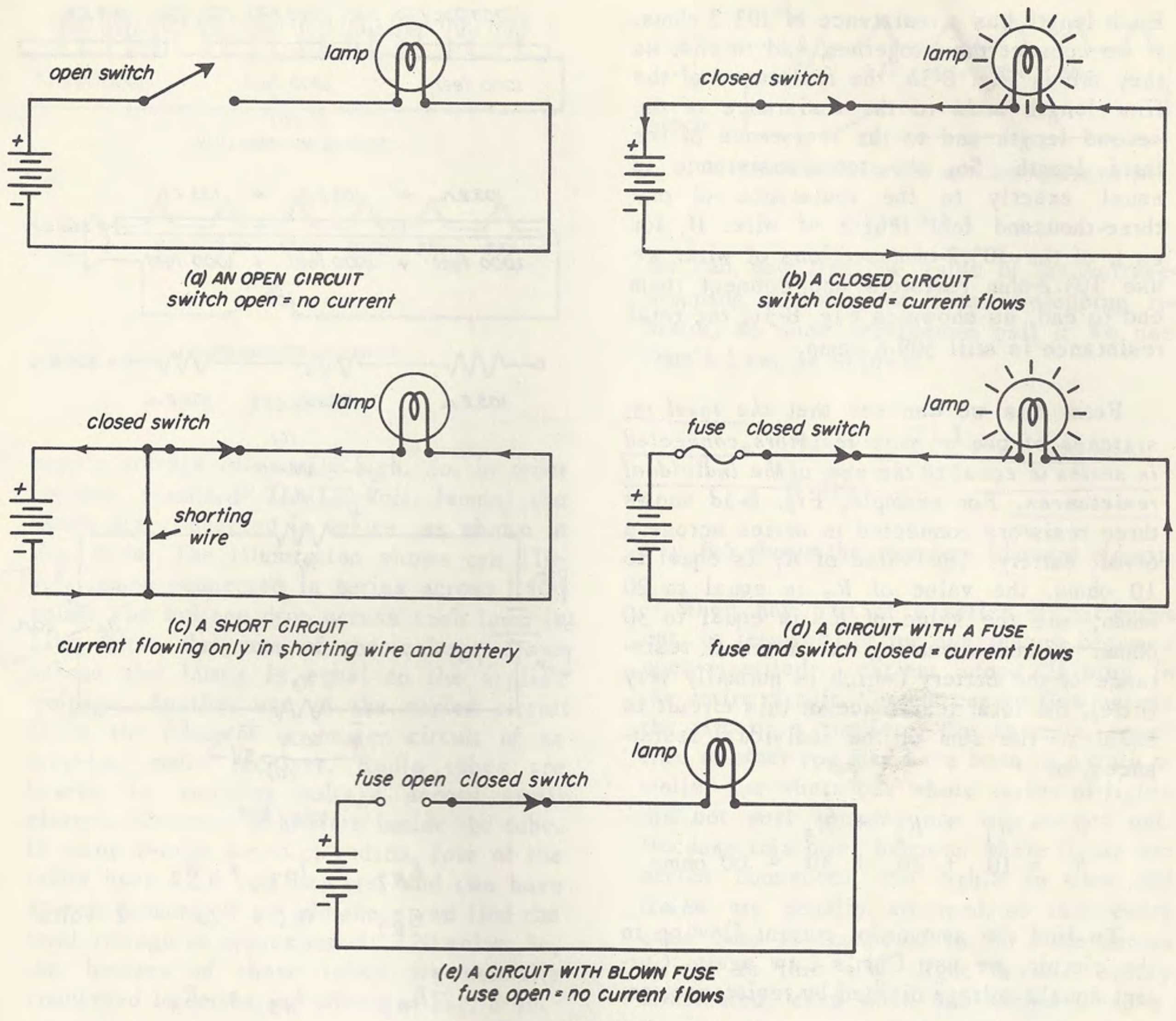


Fig. 8-1

In the last lesson, you learned that the resistance of a conductor, such as copper wire, is in proportion to the length of the conductor. For example, the resistance of one thousand feet of No. 30 copper wire is equal to 103.2 ohms. The resistance of two thousand feet of the same wire is equal to twice 103.2 ohms, or 206.4 ohms. The resistance of three thousand feet is equal to three times 103.2 ohms, or 309.6 ohms. Suppose we have three separate one thousand-foot lengths of this wire, as shown in Fig. 8-3*a*.

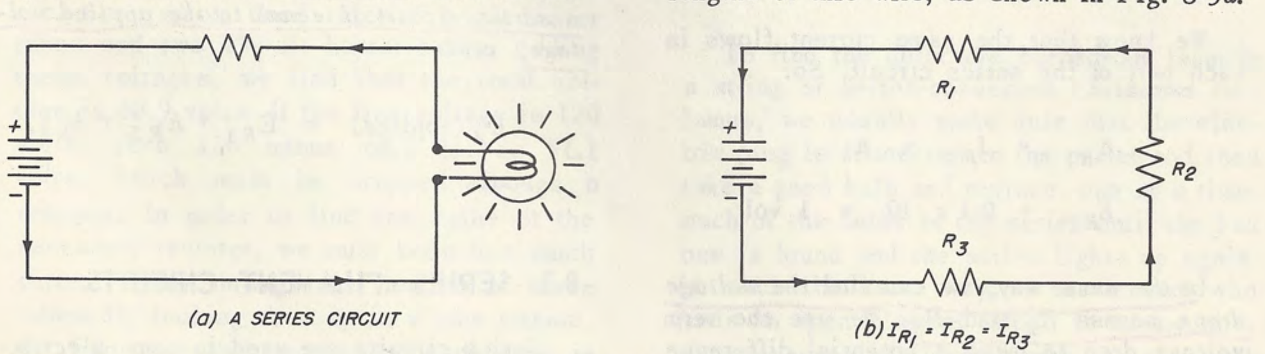


Fig. 8-2

Each length has a resistance of 103.2 ohms. If we connect them together, end to end, as they are in Fig. 8-3*b*, the resistance of the first length adds to the resistance of the second length and to the resistance of the third length. So, the total resistance is equal exactly to the resistance of one three-thousand foot length of wire. If, for each of the 103.2-ohm sections of wire, we use 103.2-ohm resistors and connect them end to end, as shown in Fig. 8-3*c*, the total resistance is still 309.6 ohms.

From this we can see that *the total resistance of two or more resistors connected in series is equal to the sum of the individual resistances.* For example, Fig. 8-3*d* shows three resistors connected in series across a 6-volt battery. The value of R_1 is equal to 10 ohms, the value of R_2 is equal to 20 ohms, and the value of R_3 is equal to 30 ohms. Without counting the internal resistance of the battery (which is normally very little), the total resistance of this circuit is equal to the sum of the individual resistances, or

$$R_t = R_1 + R_2 + R_3$$
$$R_t = 10 + 20 + 30 = 60 \text{ ohms}$$

To find the amount of current flowing in the circuit, we use Ohm's Law again. Current equals voltage divided by resistance, or:

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{6}{60} = 0.1 \text{ ampere}$$

We know that the same current flows in each part of the series circuit. So:

$$E_{R1} = I_{R1} \times R_1$$
$$E_{R1} = 0.1 \times 10 = 1 \text{ volt}$$

In the same way, we can find the *voltage drops* across R_2 and R_3. We use the term voltage drop to mean a potential difference or a difference in voltage.

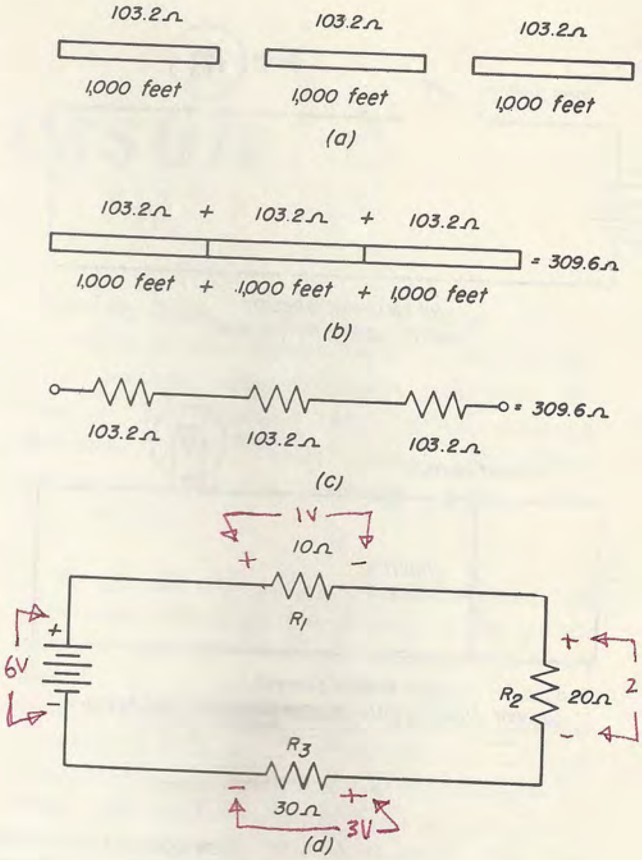


Fig. 8-3

$$E_{R2} = I_{R2} \times R_2$$
$$E_{R2} = 0.1 \times 20 = 2 \text{ volts}$$

$$E_{R3} = I_{R3} \times R_3$$
$$E_{R3} = 0.1 \times 30 = 3 \text{ volts}$$

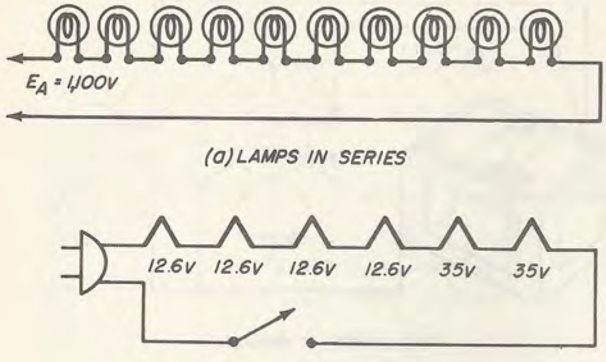
If we add the voltage drops across R_1, R_2, and R_3, we find that the sum is 6 volts, which is exactly equal to the *applied voltage* (battery voltage). From this, we can make another rule: *The sum of the voltage drops in a series circuit is equal to the applied voltage,* or:

$$E_A \text{ (applied)} = E_{R1} + E_{R2} + E_{R3},$$

etc.

8-3. SERIES FILAMENT CIRCUITS

Series circuits are used in some electric-railway or trolley-car lighting systems. The



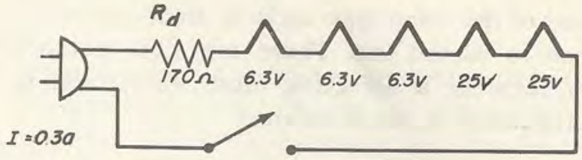
(a) LAMPS IN SERIES

(b) FILAMENTS IN SERIES

Fig. 8-4

supply voltage is usually high. So, in order to use standard 110-120-volt lamps, the lamps are connected in series, as shown in Fig. 8-4*a*. The illustration shows ten 110-volt lamps connected in series across 1,100 volts. The voltage drop across each lamp is 110 volts; the sum of the voltage drops across the lamps is equal to the applied voltage. Another use of the series circuit is in the filament or heater circuit of an a.c.-d.c. radio receiver. Radio tubes are heated by applying voltage across small electric filaments or heaters inside the tube. In many 6-tube a.c.-d.c. radios, four of the tubes have 12.6 volt heaters, and two have 35-volt heaters. If we add these, we find the total voltage is approximately 120 volts. So, the heaters of these tubes are normally connected in series, as shown in Fig. 8-4*b*.

In some cases, the heater voltages of the tubes used in an a.c-d.c. receiver do not add up to the line voltage. In such cases, it is necessary to place a resistor in series with the filaments in order to drop the voltage to the amount needed to heat the filaments. For example, some of the earlier a.c.-d.c. radios used three 6.3-volt heater tubes and two 25-volt heater tubes. Adding these voltages, we find that the total voltage is 68.9 volts. If the line voltage is 120 volts, then 120 minus 68.9 leaves 51.1 volts, which must be dropped through a resistor. In order to find the value of the necessary resistor, we must know how much current flows through the heaters of these tubes. By looking them up in a tube manual, we find that the current for each tube is 300 ma, or 0.3 amperes. With this information,



FILAMENTS IN SERIES WITH DROPPING RESISTOR

Fig. 8-5

we can now find the value of the voltage-dropping resistor, or filament-dropping resistor, as some servicemen call it We use Ohm's Law, as follows:

$$R_d = \frac{E_{Rd}}{I_{R\ fil}} = \frac{51.1}{0.3} = 170 \text{ ohms}$$

Fig. 8-5 shows the complete filament circuit.

When any part of a series circuit burns out, is removed, or for any reason becomes open-circuited, current stops flowing in the entire circuit. Current cannot flow unless the circuit is complete. For example, sometime or other you may have been in a train or trolley car where one whole series of lights did not work because one was burned out. Because this often happens where lights are series connected, the lights in cars and trains are usually arranged so that every other lamp is connected to the same series string. In this way, light is still evenly distributed, even when one series is open. You may have seen lights series-connected on a Christmas tree. Then, when one light became loosened or burned out, all the lights in the series went out. In any radio that uses a series filament or heater circuit, when one tube burns out or is removed from its socket, all of the tubes stop glowing because the circuit is broken.

To find the defective burned-out lamp in a string of series-connected Christmas tree lamps, we usually make sure that the electric plug is connected to the outlet and then take a good bulb and replace, one at a time, each of the bulbs in the series until the bad one is found and the series lights up again. In much the same way, a serviceman who finds an open filament circuit in an a.c.-d.c. series-connected circuit may replace each of the tubes of the set, one at a time, with

one of the same type until he finds out which one is burned out. There are other methods of locating a defective tube, which will be discussed in other lessons.

8-4. PARALLEL CIRCUITS

In Fig. 8-6, a lamp is connected to the terminals of a 6-volt storage battery. The current flowing in this simple circuit is 0.15 ampere. The voltage across the lamp is 6 volts. If we wish, we may calculate the resistance of the filament in the lamp (when hot) by using Ohm's Law.

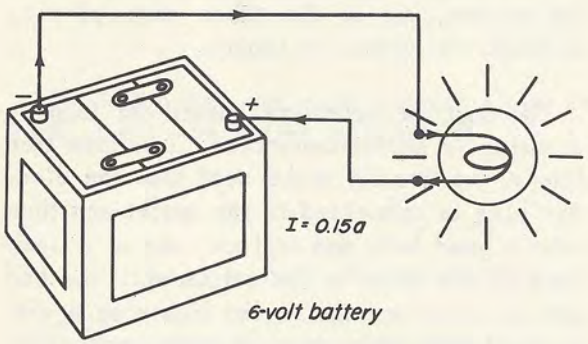
$$R = \frac{E}{I}$$

$$R = 6 \div 0.15$$

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

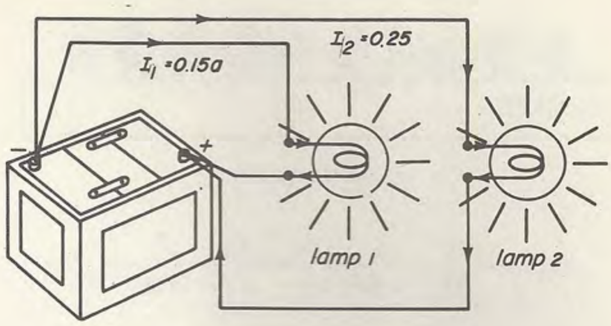
This circuit is called a *simple circuit.* It is *not* a series circuit. *The lamp is considered to be across the terminals or in parallel with the terminals of the storage battery and not in series with them.* This is an important fact.

Let us connect another lamp to the battery, as shown in Fig. 8-7. This lamp draws 0.25 ampere. The current flowing through lamp #1 flows from the negative terminal of the battery through the connecting wire to the lamp, then through the connecting wire to the positive terminal of the battery. The



A SIMPLE CIRCUIT

Fig. 8-6



TWO LAMPS IN PARALLEL

Fig. 8-7

current flowing through lamp #2 flows through a connecting wire from the negative terminal of the battery, through the lamp, and through the connecting wire to the positive terminal of the battery. The current in lamp #1 is not the same as the current flowing in lamp #2. The total current drawn from the battery is equal to the current flowing through lamp #1 added to the current flowing through lamp #2. Therefore:

$$I_t = I_1 + I_2$$

$$I_t = 0.15 + 0.25 = 0.40 \text{ ampere}$$

Lamp #2 *has the* same 6 volts across it as lamp #1 has. So, we may calculate the resistance of lamp #2 (when hot) by:

$$R_{L2} = \frac{E}{I_2}$$

$$R_{L2} = \frac{6}{0.25} = 24 \text{ ohms}$$

Because there are two separate paths in which current flows, this is not a series circuit. Instead, it is called a *parallel circuit.* A *parallel circuit* is one that has two or more branches (paths) where one terminal from each branch is connected electrically to a common potential of the same polarity and where the remaining terminal of each branch is connected electrically to a common potential of opposite polarity.

In Fig. 8-8, three resistors are connected in parallel. The voltage between points *A* and *B* is equal to the voltage of the battery –

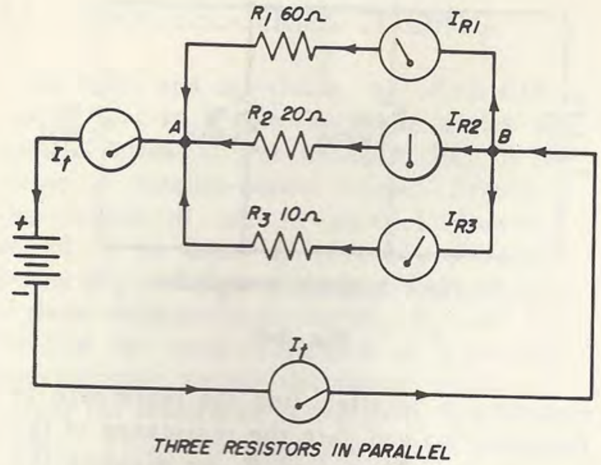


Fig. 8-8

6 volts. So, the voltage across R_1 is the same as the voltage R_2 and the same as the voltage across R_3. This enables us to write our first rule for parallel circuits: *The voltage across one branch of a parallel circuit is the same as the voltage across any other branch and is equal to the applied voltage.*

Using Ohm's Law, we find the current flowing in each of the three parallel branches as follows:

$$I_{R1} = \frac{E_{R1}}{R_1} = \frac{6}{60} = 0.1 \text{ ampere}$$

$$I_{R2} = \frac{E_{R2}}{R_2} = \frac{6}{20} = 0.3 \text{ ampere}$$

$$I_{R3} = \frac{E_{R3}}{R_3} = \frac{6}{10} = 0.6 \text{ ampere}$$

The current flowing from the negative terminal of the battery to point B and the current flowing from point A to the positive terminal of the battery is the total current and is equal to the sum of the branch currents. Thus:

$$I_t = I_{R1} + I_{R2} + I_{R3}$$

$$I_t = 0.1 + 0.3 + 0.6$$

$$= 1.0 \text{ ampere}$$

This permits us to write the second rule for parallel circuits: *The total current in a parallel circuit is equal to the sum of the currents flowing in the individual branches.*

8-5. TOTAL RESISTANCE OF A PARALLEL CIRCUIT

Knowing the total current flowing at the terminals of the battery, we can use Ohm's Law to calculate the total resistance between points A and B:

$$R_t = \frac{E}{I_t} = \frac{6}{1} = 6 \text{ ohms}$$

So, a 60-ohm, a 20-ohm, and a 10-ohm resistor connected in parallel have a total resistance *less* than the value of any one of the resistors by itself. To find the total resistance of two or more resistors connected in parallel, we cannot add them as we do when they are connected in series. Instead, we use a different formula.

Of course, we know that the total resistance of a parallel circuit is equal to the total voltage divided by the total current, but this is not very helpful when we want to know, for example, what value of resistance we get when we combine two resistors in parallel. One formula that we can use, once in a while, says: *The total resistance of equal resistors in parallel is equal to the value of one of the resistors divided by the number of them connected in parallel.* For example, two 500-ohm resistors connected in parallel have a resistance equal to 500 (the value of one of the equal resistors in parallel), divided by 2 (the number of resistors), or 250 ohms. We find the total resistance of four 600-ohm resistors in parallel similarly:

$$R_t = \frac{600}{4} = 150 \text{ ohms}$$

Of course, this formula can be used only when we connect resistors of equal value in parallel.

Another formula we can use is: *The total resistance of any two resistors connected in parallel is equal to their product divided by their sum.* Or:

$$R_t = \frac{\text{Product}}{\text{sum}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

For example, let R_1 equal 20 ohms and R_2 equal 60 ohms. Then:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{20 \times 60}{20 + 60}$$

$$= \frac{1200}{80} = 15 \text{ ohms}$$

This is the easiest and most popular method used to find the total resistance of resistors connected in parallel. It may be used to find the total resistance of three or more resistors connected in parallel by working in two or more steps. For example, Fig. 8-9 shows three resistors connected in parallel. To find the total resistance of this circuit, we find the resistance of two of the parallel resistors first. Then, we find the total resistance by finding the product of this resistance and the resistance of the remaining resistor over the sum of the two resistances.

For example:

$$R_{1\&2} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{240 \times 80}{240 + 80}$$

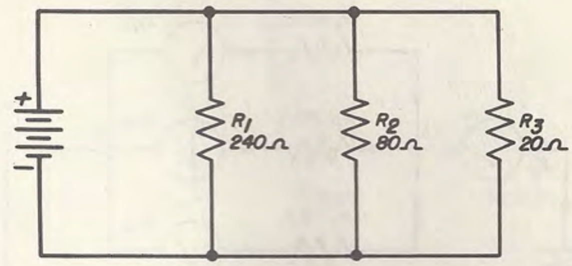
$$= \frac{19{,}200}{320} = 60 \text{ ohms}$$

then:

$$R_t = \frac{R_{1\&2} \times R_3}{R_{1\&2} + R_3} = \frac{60 \times 20}{60 + 20}$$

$$= \frac{1{,}200}{80} = 15 \text{ ohms}$$

To find the total resistance of four



THREE RESISTORS IN PARALLEL

Fig. 8-9

resistors in parallel, find the resistance of the first two and then the resistance of the second two. Then find R_t by dividing the product of the two answers by the sum of the two answers.

Reciprocal Method. The total resistance of two or more resistors connected in parallel may be found by still another method. We call it the *reciprocal method*. The *reciprocal* of any value or number, as you know, is equal to 1 divided by the value or the number. For example, the reciprocal of 25 is equal to 1 divided by 25 (1/25), which equals 0.04. Using the reciprocal method, R_t is equal to:

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

To see how this formula works, let's use it to find the total resistance of the three resistors in Fig. 8-9, the same value that we just found by the product-over-the-sum method.

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{1}{\frac{1}{240} + \frac{1}{80} + \frac{1}{20}}$$

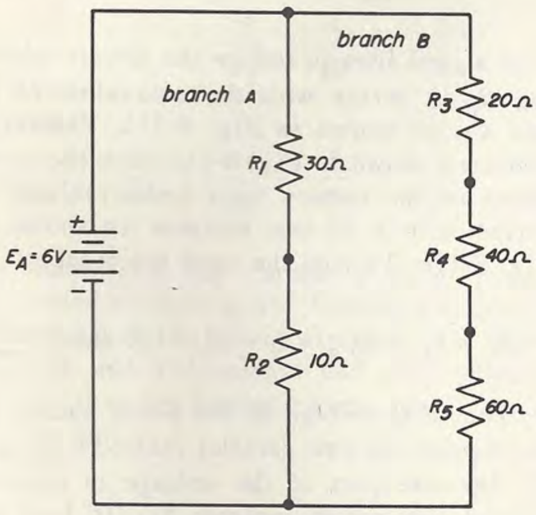
Next we must find the common denominator, which is 240:

$$R_t = \frac{1}{\frac{1}{240} + \frac{3}{240} + \frac{12}{240}} = \frac{1}{\frac{16}{240}}$$

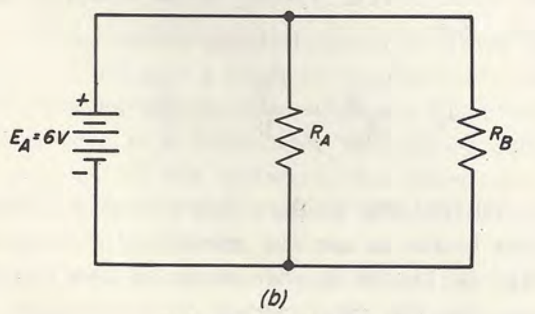
$$= 1 \times \frac{240}{16} = 15 \text{ ohms}$$

8-6. PARALLEL-SERIES CIRCUITS

In radio and television, we often find a circuit that is a combination of series and parallel circuits. For example, Fig. 8-10*a* shows a parallel-series circuit. Branch *A* and branch *B* are in parallel. However, branch *A* is made up of two resistors in series (R_1 and R_2), while branch *B* consists of three resistors in series (R_3, R_4, and R_5). To find the total resistance of a parallel-series circuit, we use the series circuit rules to find the resistance of the parts that are in series. Then we must apply the parallel circuit rules to find the resistance of the parallel branches. The order in which these rules are applied depends upon what is known about the circuit. For example, if the value of each resistor is given, as in the circuit shown in Fig. 8-10*a*, we first find the total series resistance in each branch before we find the total resistance of the parallel branches. So:



(a)



(b)

PARALLEL-SERIES CIRCUIT

Fig. 8-10

$$R_{\text{Branch } A} = R_1 + R_2 = 30 + 10 = 40 \text{ ohms}$$

$$R_{\text{Branch } B} = R_3 + R_4 + R_5 = 20 + 40 + 60 = 120 \text{ ohms}$$

Fig. 8-10*b* shows the resistance of each branch as a single resistance. To find the total resistance of the two branches we use the product over sum method. So:

$$R_t = \frac{R_{\text{Branch } A} \times R_{\text{Branch } B}}{R_{\text{Branch } A} + R_{\text{Branch } B}} = \frac{40 \times 120}{40 + 120} = \frac{4800}{160} = 30 \text{ ohms}$$

Let's take another look at the circuit shown in Fig. 8-10*a*. The voltage of the battery is 6 volts. From the drawing and from the parallel circuit rules, we know that the total voltage (6 volts) appears across Branch *A* and across Branch *B*. However the total voltage does not appear across either R_1 or R_2 or across any one of the resistors in Branch *B*. For example, part of the 6-volts appears across R_1. The rest of the 6-volts appears across R_2. To know how much is across each resistor, it is necessary to know first how much current flows in Branch *A*. To find this, we use Ohm's Law. So:

$$I_A = \frac{E_A}{R_A} = \frac{6}{40} = 0.15 \text{ ampere}$$

Therefore, the current flowing in Branch *A* and resistors R_1 and R_2 is equal to 0.15 amperes. To find the voltage across R_1, we use Ohm's Law:

$$E_{R1} = I_{R1} \times R_1 = 0.15 \times 30 = 4.5 \text{ volts}$$

and to find the voltage across R_2:

$$E_{R2} = I_{R2} \times R_2 = 0.15 \times 10 = 1.5 \text{ volts}$$

In the same way, we can find the voltages across R_3, R_4 and R_5 in Branch *B*. First we

must find the current flowing in Branch B:

$$I_B = \frac{E_B}{R_B} = \frac{6}{120} = 0.05 \text{ ampere}$$

Therefore, the current flowing through Branch B and resistors R_3, R_4, and R_5 equals 0.05 ampere. So:

$$E_{R3} = I_{R3} \times R_3 = 0.05 \times 20 = 1 \text{ volt}$$

$$E_{R4} = I_{R4} \times R_4 = 0.05 \times 40 = 2 \text{ volts}$$

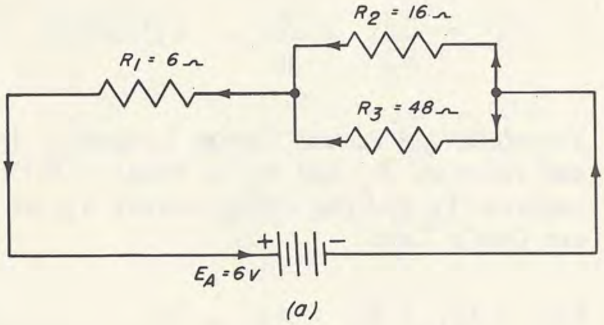
$$E_{R5} = I_{R5} \times R_5 = 0.05 \times 60 = 3 \text{ volts}$$

We can check our answer by adding E_{R3}, E_{R4}, and E_{R5}:

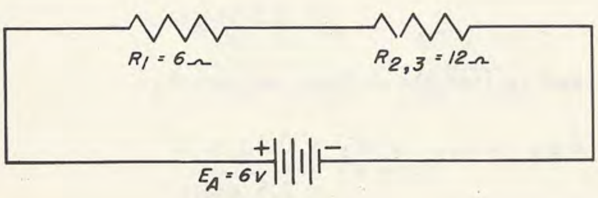
$$1 + 2 + 3 = 6 \text{ volts}$$

We know the answer is right when the sum of the voltage drops of the branch is equal to the voltage across the branch.

There are many kinds of parallel-series circuits; therefore a general order of steps for solving all such circuits cannot be given. Much depends upon the particular circuit and the information available about the circuit. However, most of these circuits may be solved by applying Ohm's Law and the rules for series and parallel circuits.



(a)



(b)

Fig. 8-11

8-7. SERIES-PARALLEL CIRCUITS

A series-parallel circuit is made up of one or more groups of parallel resistors in series with each other or in series with one or more single resistors. Fig. 8-11*a* shows the simplest form of series-parallel circuit. It shows a single resistor (R_1) in series with two resistors (R_2 and R_3) in parallel. To complete the circuit, this combination is connected to the terminals of a 6-volt battery. To find the total resistance offered by these three resistors, we need to apply, once again, the rules for both series and parallel circuits. To begin, we must find the equivalent resistance of 16 ohms in parallel with 48 ohms. So:

$$R_{2,3} = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{16 \times 48}{16 + 48}$$

$$= \frac{768}{64} = 12 \text{ ohms}$$

It is a good idea to redraw the circuit, showing R_1 in series with the equivalent of R_2 and R_3, as shown in Fig. 8-11*b*. The three resistors shown in Fig. 8-11*a* have the same effect on the battery as a 6-ohm resistor in series with a 12-ohm resistor as shown in Fig. 8-11*b*. To find the total resistance:

$$R_t = R_1 + R_{2,3} = 6 + 12 = 18 \text{ ohms}$$

The total voltage of the 6-volt battery is not across the two parallel resistors R_2 and R_3 because part of the voltage is dropped through the series resistor R_1. To find the voltage across each resistor, we first find the total current flowing in the complete circuit. So:

$$I_t = \frac{E_A}{R_t} = \frac{6}{18} = \frac{1}{3} \text{ ampere}$$

To find the voltage drops in this circuit, it is better to use the simplified drawing in Fig. 8-11*b*. In this drawing, we can readily see that the total current flows through R_1 and the equivalent resistance of R_2 and R_3. Therefore,

$$E_{R1} = I_{R1} \times R_1 = \frac{1}{3} \times 6 = 2 \text{ volts}$$

To find the voltage across the parallel pair, we could just subtract the voltage across R_1 from the applied voltage (6 – 2 = 4 volts). However, to prove it, we use Ohm's Law:

$$E_{R2,3} = I_{R2,3} \times R_{2,3} = \frac{1}{3} \times 12 = 4 \text{ volts}$$

Looking at Fig. 8-11*a*, we know that the current travels from the negative terminal of the battery and divides, part going through R_2 and the rest going through R_3. The sum of these two currents flows through R_1 and returns to the positive terminal of the battery. To find how much current flows through R_2 and how much current flows through R_3, we can again use Ohm's Law:

$$I_{R2} = \frac{E_{R2}}{R_2} = \frac{4}{16} = \frac{1}{4}$$

and

$$I_{R3} = \frac{E_{R3}}{R_3} = \frac{4}{48} = \frac{1}{12}$$

We know that the current flowing through R_2 added to the current flowing through R_3 should equal the total current I_t. To check this we add 1/4 ampere and 1/12 ampere. We see that the lowest common denominator is 12, so:

$$\frac{1}{4} + \frac{1}{12} = \frac{3}{12} + \frac{1}{12} = \frac{4}{12} = \frac{1}{3} \text{ ampere}$$

Another series-parallel circuit is shown in Fig. 8-12. It looks a lot more complicated than the first series-parallel circuit. However, while there is a little more work to be done in getting all the answers, the same rules apply; it really isn't much more difficult than the first circuit. Before we try to find out the total resistance of a circuit like this, it is necessary to examine the circuit carefully and to lay out a plan of action. To find the total resistance of a series-parallel circuit, where all of the individual resistor values are known, it is usually best to start working with the resistors farthest away from the source of voltage. Let's see why this is so. If we examine the path of current flow from the negative electrode of the battery, we find that current flows through R_3 and divides at point *A;* part of it flows through R_2 and the rest flows through R_5 and R_4. These two currents come together at point *B* and flow through R_1 to the positive terminal of the battery. So, if we want to treat R_1, R_2, and R_3 as a series circuit, whose total resistance must be found first, we find that we cannot. We know that the same current flows through each part in a series circuit. We also know that R_2 carries only part of the current flowing through R_1 and R_3. Therefore, R_1, R_2, and R_3 do not make a series circuit. However, we do know that the current divides, part flowing through R_2 and the rest through R_5 and R_4. It looks therefore, as if R_2 and the combination of R_4 and R_5 are in parallel, which is the case. This being so, it is necessary to find the equivalent resistance of these two parallel branches. To do this, we must first find the total value of R_4 and R_5 in series. This brings us back to our first statement, that we usually start with the resistors farthest from the source of voltage. These resistors are R_4 and R_5. Therefore:

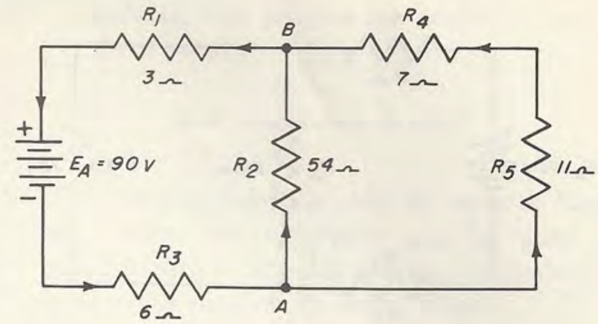


Fig. 8-12

$$R_{4,5} = R_4 + R_5 = 7 + 11 = 18 \text{ ohms}$$

At this point, it is a good idea to make a simplified drawing like the one as shown in

must find the current flowing in Branch B:

$$I_B = \frac{E_B}{R_B} = \frac{6}{120} = 0.05 \text{ ampere}$$

Therefore, the current flowing through Branch B and resistors R_3, R_4, and R_5 equals 0.05 ampere. So:

$$E_{R3} = I_{R3} \times R_3 = 0.05 \times 20 = 1 \text{ volt}$$

$$E_{R4} = I_{R4} \times R_4 = 0.05 \times 40 = 2 \text{ volts}$$

$$E_{R5} = I_{R5} \times R_5 = 0.05 \times 60 = 3 \text{ volts}$$

We can check our answer by adding E_{R3}, E_{R4}, and E_{R5}:

$$1 + 2 + 3 = 6 \text{ volts}$$

We know the answer is right when the sum of the voltage drops of the branch is equal to the voltage across the branch.

There are many kinds of parallel-series circuits; therefore a general order of steps for solving all such circuits cannot be given. Much depends upon the particular circuit and the information available about the circuit. However, most of these circuits may be solved by applying Ohm's Law and the rules for series and parallel circuits.

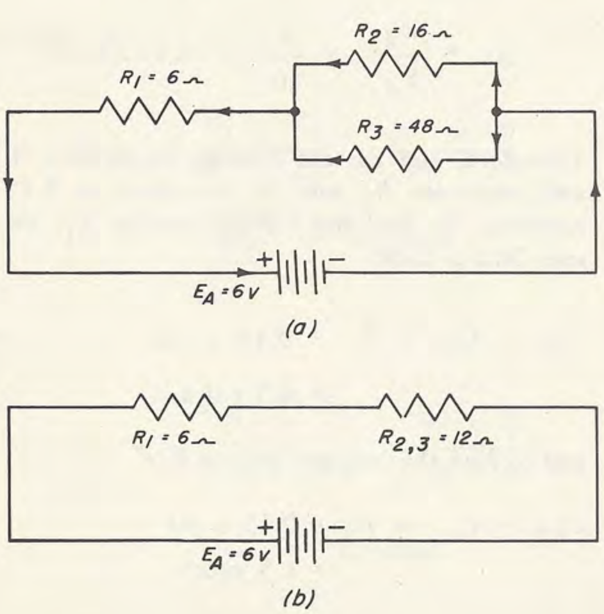


Fig. 8-11

8-7. SERIES-PARALLEL CIRCUITS

A series-parallel circuit is made up of one or more groups of parallel resistors in series with each other or in series with one or more single resistors. Fig. 8-11*a* shows the simplest form of series-parallel circuit. It shows a single resistor (R_1) in series with two resistors (R_2 and R_3) in parallel. To complete the circuit, this combination is connected to the terminals of a 6-volt battery. To find the total resistance offered by these three resistors, we need to apply, once again, the rules for both series and parallel circuits. To begin, we must find the equivalent resistance of 16 ohms in parallel with 48 ohms. So:

$$R_{2,3} = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{16 \times 48}{16 + 48}$$

$$= \frac{768}{64} = 12 \text{ ohms}$$

It is a good idea to redraw the circuit, showing R_1 in series with the equivalent of R_2 and R_3, as shown in Fig. 8-11*b*. The three resistors shown in Fig. 8-11*a* have the same effect on the battery as a 6-ohm resistor in series with a 12-ohm resistor as shown in Fig. 8-11*b*. To find the total resistance:

$$R_t = R_1 + R_{2,3} = 6 + 12 = 18 \text{ ohms}$$

The total voltage of the 6-volt battery is not across the two parallel resistors R_2 and R_3 because part of the voltage is dropped through the series resistor R_1. To find the voltage across each resistor, we first find the total current flowing in the complete circuit. So:

$$I_t = \frac{E_A}{R_t} = \frac{6}{18} = \frac{1}{3} \text{ ampere}$$

To find the voltage drops in this circuit, it is better to use the simplified drawing in Fig. 8-11*b*. In this drawing, we can readily see that the total current flows through R_1 and the equivalent resistance of R_2 and R_3. Therefore,

$$E_{R1} = I_{R1} \times R_1 = \frac{1}{3} \times 6 = 2 \text{ volts}$$

To find the voltage across the parallel pair, we could just subtract the voltage across R_1 from the applied voltage (6 – 2 = 4 volts). However, to prove it, we use Ohm's Law:

$$E_{R2,3} = I_{R2,3} \times R_{2,3} = \frac{1}{3} \times 12 = 4 \text{ volts}$$

Looking at Fig. 8-11*a*, we know that the current travels from the negative terminal of the battery and divides, part going through R_2 and the rest going through R_3. The sum of these two currents flows through R_1 and returns to the positive terminal of the battery. To find how much current flows through R_2 and how much current flows through R_3, we can again use Ohm's Law:

$$I_{R2} = \frac{E_{R2}}{R_2} = \frac{4}{16} = \frac{1}{4}$$

and

$$I_{R3} = \frac{E_{R3}}{R_3} = \frac{4}{48} = \frac{1}{12}$$

We know that the current flowing through R_2 added to the current flowing through R_3 should equal the total current I_t. To check this we add 1/4 ampere and 1/12 ampere. We see that the lowest common denominator is 12, so:

$$\frac{1}{4} + \frac{1}{12} = \frac{3}{12} + \frac{1}{12} = \frac{4}{12} = \frac{1}{3} \text{ ampere}$$

Another series-parallel circuit is shown in Fig. 8-12. It looks a lot more complicated than the first series-parallel circuit. However, while there is a little more work to be done in getting all the answers, the same rules apply; it really isn't much more difficult than the first circuit. Before we try to find out the total resistance of a circuit like this, it is necessary to examine the circuit carefully and to lay out a plan of action. To find

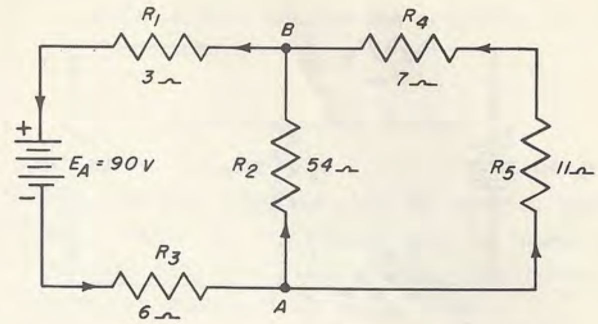


Fig. 8-12

the total resistance of a series-parallel circuit, where all of the individual resistor values are known, it is usually best to start working with the resistors farthest away from the source of voltage. Let's see why this is so. If we examine the path of current flow from the negative electrode of the battery, we find that current flows through R_3 and divides at point *A*; part of it flows through R_2 and the rest flows through R_5 and R_4. These two currents come together at point *B* and flow through R_1 to the positive terminal of the battery. So, if we want to treat R_1, R_2, and R_3 as a series circuit, whose total resistance must be found first, we find that we cannot. We know that the same current flows through each part in a series circuit. We also know that R_2 carries only part of the current flowing through R_1 and R_3. Therefore, R_1, R_2, and R_3 do not make a series circuit. However, we do know that the current divides, part flowing through R_2 and the rest through R_5 and R_4. It looks therefore, as if R_2 and the combination of R_4 and R_5 are in parallel, which is the case. This being so, it is necessary to find the equivalent resistance of these two parallel branches. To do this, we must first find the total value of R_4 and R_5 in series. This brings us back to our first statement, that we usually start with the resistors farthest from the source of voltage. These resistors are R_4 and R_5. Therefore:

$$R_{4,5} = R_4 + R_5 = 7 + 11 = 18 \text{ ohms}$$

At this point, it is a good idea to make a simplified drawing like the one as shown in

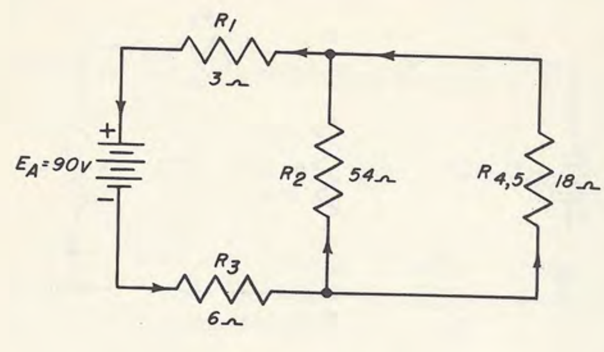


Fig. 8-13

Fig. 8-13. With such a drawing, we can see that the next step is to find the equivalent resistance of 54 ohms in parallel with 18 ohms: So:

$$R_{2,4,5} = \frac{R_2 \times R_{4,5}}{R_2 + R_{4,5}} = \frac{54 \times 18}{54 + 18} = \frac{972}{72}$$

$$= 13.5 \text{ ohms}$$

Again, redraw the circuit to look like the one shown in Fig. 8-14. Now we can see that all that remains is to add three resistance values to get R_t. So:

$$R_t = R_1 + R_{2,4,5} + R_3$$
$$= 3 + 13.5 + 6 = 22.5 \text{ ohms}$$

To find the total current, we use Ohm's Law:

$$I_t = \frac{E_A}{R_t} = \frac{90}{22.5} = 4 \text{ amperes}$$

At this point, it may become a little easier to understand why we should use the simplified drawings shown in Fig. 8-13 and 8-14. Suppose we want to know the voltage drops across each resistor in the circuit shown in Fig. 8-12, By using Fig. 8-14 it is easier to see that the 90 volts of the battery is divided into three parts. One part is across R_1, another part is across the equivalent resistance of $R_{2,4,5}$ and still another part is across R_3. It is also easier to see that the total current (I_t) flows through R_1 and the combination of $R_{2,4,5}$ and R_3. We must find these voltage drops by using Ohm's Law:

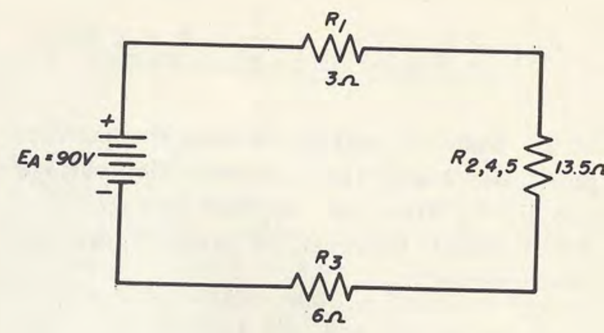


Fig. 8-14

$$E_{R1} = I_{R1} \times R_1 = 4 \times 3 = 12 \text{ volts}$$

$$E_{R2,4,5} = I_{R2,4,5} \times R_{2,4,5} = 4 \times 13.5$$
$$= 54 \text{ volts}$$

$$E_{R3} = I_{R3} \times R_3 = 4 \times 6 = 24 \text{ volts}$$

Adding these voltages, we find that 12 + 54 + 24 exactly equal the 90 volts of the battery.

Let's shift back to Fig. 8-13. We find a simple parallel combination of 54 ohms and 18 ohms. The voltage across each branch is the same. This is a very important point to remember, so that at some time or other you won't be tempted to count the voltage across parallel branches more than once. To find the current flowing in each of these parallel branches, we use Ohm's Law:

$$I_{R2} = \frac{E_{R2}}{R_2} = \frac{54}{54} = 1 \text{ ampere}$$

We can easily find the remaining current flowing through the combination of $E_{4,5}$ by subtracting the I_{R2} from the I_t (4 − 1 = 3 amperes). However, we can check our work by calculating current with Ohm's Law:

$$I_{R4,5} = \frac{E_{R4,5}}{R_{4,5}} = \frac{54}{18} = 3 \text{ amperes}$$

To find the voltage drops across R_4 and R_5, we apply Ohm's Law again:

$$E_{R4} = I_{R4} \times R_4 = 3 \times 7 = 21 \text{ volts}$$

$$E_{R5} = I_{R5} \times R_5 = 3 \times 11 = 33 \text{ volts}$$

Checking, we find that 21 + 33 = 54 volts, which is the amount we found across the parallel branches.

8-8. COMBINING RESISTORS

Servicemen sometimes find it necessary to combine two or more resistors to get a needed resistance value. Sometimes this is done by connecting two resistors in series to add their values. For example, if a 1,500-ohm resistor is needed and we have a 1,000-ohm resistor and a 500-ohm resistor, by connecting them in series we get a total resistance of 1,500 ohms. In other cases, resistors are connected in parallel to obtain a needed value. For example, two 3,000-ohm resistors connected in parallel make:

$$R = \frac{3{,}000}{2} = 1{,}500 \text{ ohms}$$

Sometimes a radioman has a resistor of a certain value and he wants to know what value of resistance may be connected in parallel with this resistor to produce a needed amount of resistance. In such cases, the following formula is used:

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

where:

R_1 = resistance of first resistor

R_2 = resistance of the resistor that, when placed in parallel with the first resistor, will produce the needed value of resistance

R_t = total resistance needed

For example: Suppose that we want to know what value of resistance may be used in parallel with a 100-ohm resistor to produce a total resistance of 25 ohms. Then:

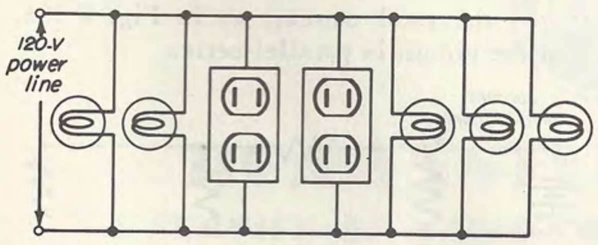
$$R_2 = \frac{R_1 \times R_t}{R_1 - R_t} = \frac{100 \times 25}{100 - 25}$$

$$= \frac{2500}{75} = 33\text{-}1/3 \text{ ohms.}$$

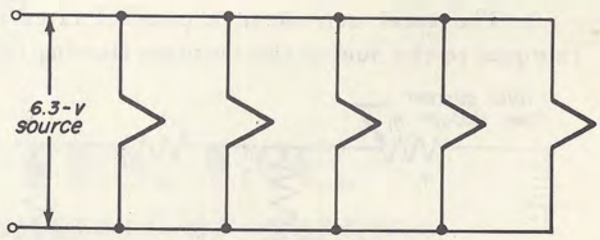
So, a 33-1/3-ohm resistor placed in parallel with a 100-ohm resistor produces a total resistance of 25 ohms.

8-9. CIRCUIT APPLICATIONS

Parallel circuits are widely used in supplying electrical power and in designing radio and television receivers. For example, most house wiring makes use of the parallel circuit. Fig. 8-15*a* shows that electric outlets and light sockets are connected in parallel across the power line. Most a-c radio and television receivers have parallel circuits supplying the heaters or filaments. A typical heater circuit is shown in Fig. 8-15*b*. One advantage of a parallel circuit is that if one lamp or tube burns out, the remaining lamps or tubes still receive power and continue to operate. For example, some Christmas tree lights are connected



(a) PARALLEL LIGHTING AND OUTLET CIRCUIT



(b) PARALLEL FILAMENT CIRCUIT

Fig. 8-15

in parallel. When the lights are so connected, it is easy to spot a burned-out light, because it just doesn't glow.

One disadvantage of parallel circuits in homes is that too many lamps or pieces of electrical apparatus may be connected to the circuit at the same time, so that too great a load is placed on the line. When this happens, more current may be drawn than the wiring is supposed to carry. If the circuit has fuses of the proper size, one or more fuses may open up. This protects the power line and even the house. For, unless the power line is properly fused, it is possible for the power line to overheat and cause a fire. If the power is supplied by a home generator, overloading the line reduces the output voltage and may shorten the life of the generator. There are many series-parallel and parallel-series combinations used in radio- and television-receiver circuits. You will meet many of them in later lessons.

SUMMARY

The three rules for series circuits are:

1. In a series circuit, the same current flows in each part of the circuit.

2. The total resistance of two or more resistors connected in series is equal to the sum of the individual resistances.

3. The sum of the voltage drops in a series circuit is equal to the applied voltage.

The laws governing parallel circuits are:

1. The voltage across each branch of a parallel circuit is the same and is equal to the applied voltage.

2. The total current in a parallel circuit is equal to the sum of the currents flowing in the individual branches.

3. The total resistance of equal resistors in parallel is equal to the value of one of the resistors divided by the number of them connected in parallel.

4. The total resistance of any two resistors connected in parallel is equal to their product divided by their sum. That is:

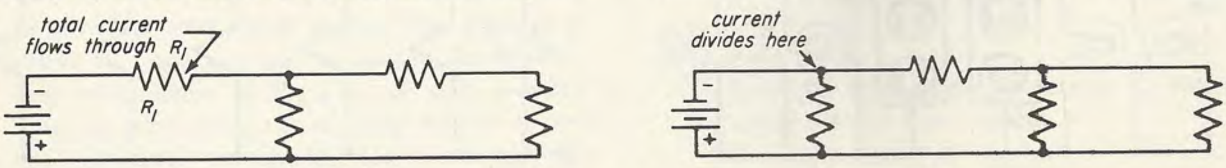
$$R_t = \frac{\text{Product}}{\text{Sum}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

5. The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances, which is written:

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

To solve d-c circuits, it is necessary for you to understand Ohm's Law and the rules given above. With this understanding, series and parallel circuits are readily solved. Without this understanding, you cannot know what rules or which Ohm's Law formula to apply to a circuit you are studying. To solve parallel-series and series-parallel circuits, use Ohm's Law; use the rules for series circuits and the rules for parallel circuits, where they apply.

One easy way to tell the difference between a series-parallel or parallel-series circuit is as follows: Examine the circuit to see whether or not the total current from the battery or other voltage source flows through any one resistor in the circuit. If the total current flows through at least one resistor, as it does through R_1 in Fig. 8-16*a*, then the circuit is series-parallel. If no resistor receives the total current, as in Fig. 8-16*b*, then the circuit is parallel-series.



(a) Series-Parallel

Fig. 8-16

(b) Parallel-Series

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 8

RESISTANCE MEASUREMENTS

RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.

Experiment Lesson 8

OBJECT

1. To complete the assembly of the ohmmeter section of your multimeter.

2. To use the ohmmeter ranges of your multimeter to measure resistance.

3. By measuring resistances in series and in parallel, to verify the theory studied in Theory Lesson 8.

PREPARATION

Examine the schematic diagram shown in Fig. 8-1 to see the electrical connections to be made in the first part of this lesson. As in previous lessons, the work already done is shown by light lines and the work to be done in this lesson is shown by heavy dark lines. In this way, you can see how the wiring you are going to do fits in with the wiring done in previous lessons.

PART ONE

EQUIPMENT NEEDED

Multimeter

Two battery clips

One 1.5-volt C-type dry cell

One 6-volt battery

One 110 k-ohm resistor

Soldering iron, cloth, and solder

Long-nose pliers

Two each of 6-32 x 3/8 inch screws and nuts

9. One medium-blade screwdriver

10. Cutting pliers

11. Hook-up wire

JOB 8-1

To mount the battery clips in the meter box, as shown in Fig. 8-2 and 8-3.

Note: Before you try to mount either battery clip, look carefully at the battery clips from your kit. Notice that one is smaller than the other. It is made to fit the small 1.5-volt C cell, while the other clip is made for the 6-volt battery. Compare these clips with those shown in Fig. 8-3; note where each clip is placed when properly mounted. Then make sure that you mount each clip on the side on which it is supposed to go.

Procedure.

Step 1. Insert 6-32 x 3/8-inch screw from the outside of the box into the hole shown in Fig. 8-2, pushing it toward the inside of the box as far as it will go. Hold it in place with your finger.

Step 2. Holding one of the battery clips in the direction shown, mount the battery clip to the side of the meter case, using the screw that you are holding with your finger, the hole in the battery clip, and one 6/32 nut. Hold the nut in place with your long-nose pliers as you tighten the screw with your screwdriver.

Step 3. Mount the second battery clip to the other side of the meter box, as shown in Fig. 8-3.

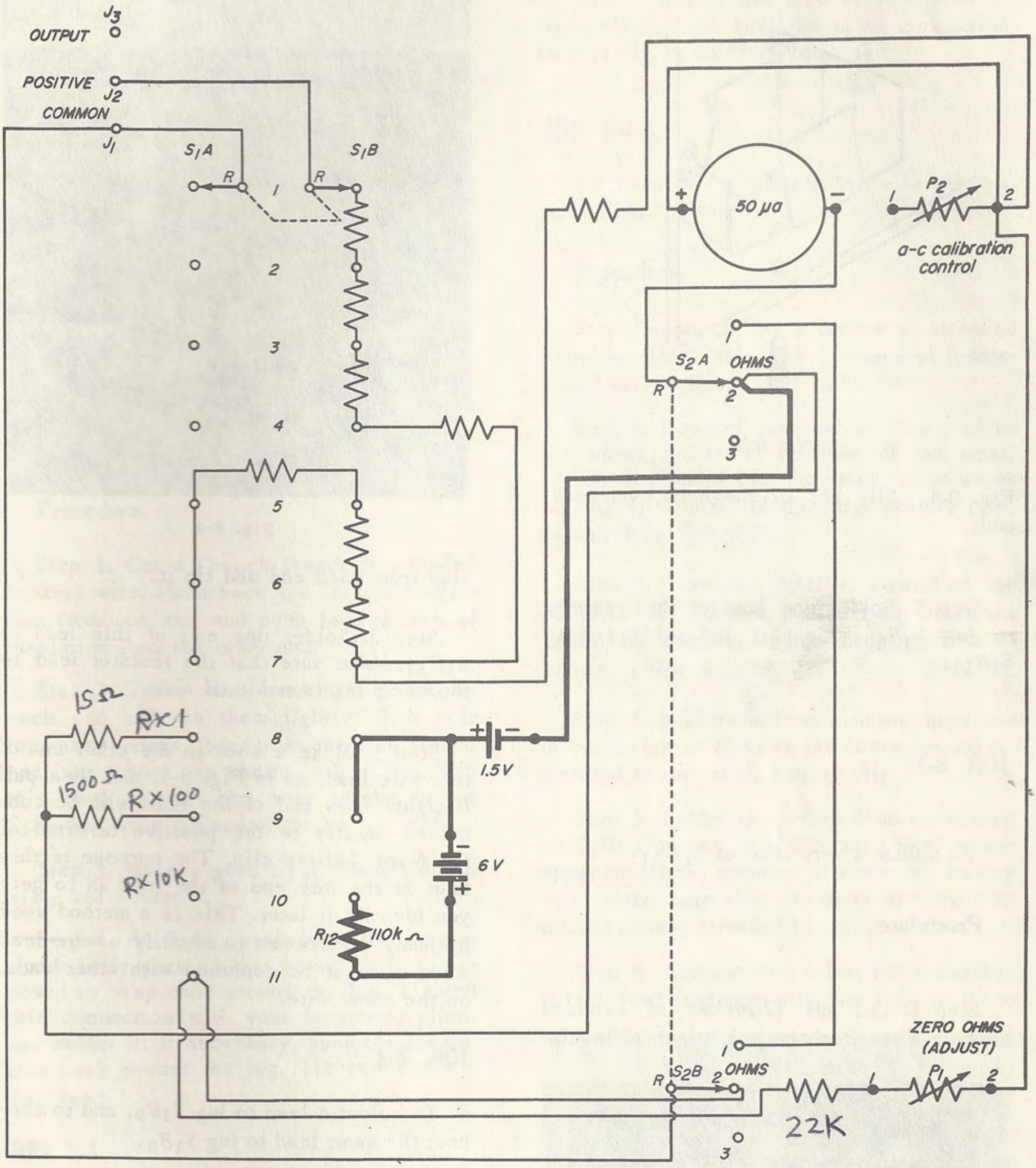


Fig. 8-1

JOB 8-2

To mount 110 k-ohm resistor R_{12}.

Procedure.

Step 1. Prepare the 110 k-ohm resistor R_{12} by removing 3/4-inch of wire from each end with your cutting pliers. If necessary, clean the resistor leads lightly with fine sandpaper. Do not remove the tinning.

Step 2. With your long-nose pliers, bend the resistor leads into the shape shown in

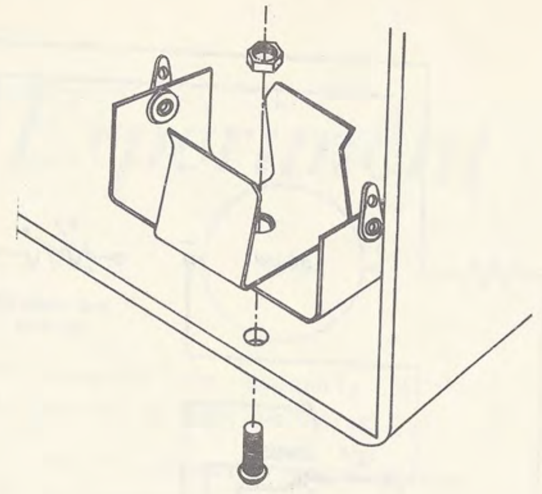


Fig. 8-2

Fig. 8-4. Slip 1/2" of spaghetti over each end.

Step 3. Solder one lead of this resistor to lug S_1B_{10}. Connect the other end to S_1B_{11}.

JOB 8-3

To solder a wire lead to S_1B_{11}.

Procedure.

Step 1. Cut off 12-inches of stranded hook-up wire. Push back 1/4-inch of insula-

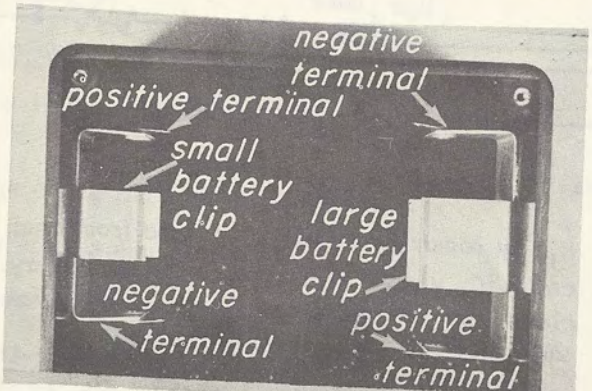


Fig. 8-3

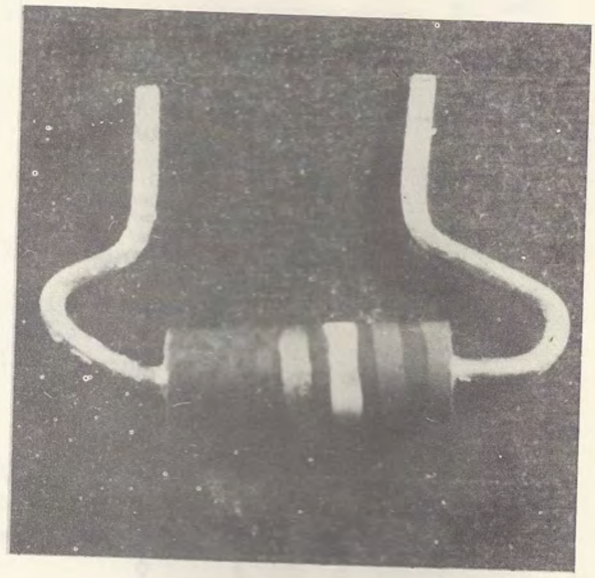


Fig. 8-4

tion from each end and tin it.

Step 2. Solder one end of this lead to S_1B_{11}. Make sure that the resistor lead to the same lug is soldered also.

Step 3. Make a knot in the other end of this wire lead, as in Fig. 8-5, and then pull it tight. This end of the lead will be connected shortly to the positive terminal of the 6-volt battery clip. The purpose of this knot at the free end of the lead is to help you identify it later. This is a method used by many servicemen to identify a wire lead when it might be confused with other leads on the same wire.

JOB 8-4

To solder a lead to lug S_1B_9, and to connect the same lead to lug S_1B_8.

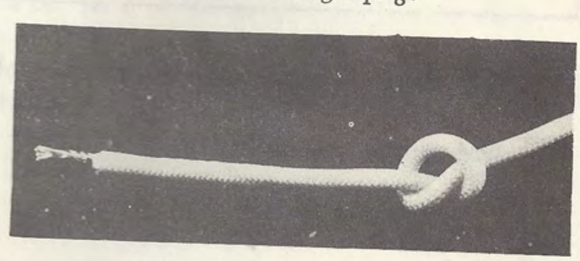


Fig. 8-5

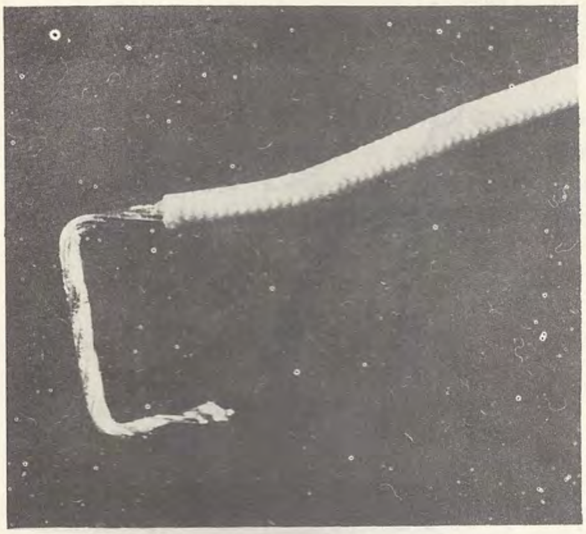


Fig. 8-6

Procedure.

Step 1. Cut a 12-inch length of stranded hook-up wire. Push back 1/4 inch of insulation from one end and push back 1 inch of insulation from the other end.

Step 2. Twist the strands together on each end and tin them lightly. With your long-nose pliers, bend the one-inch tinned end into a hook, as shown in Fig. 8-6. Slip this hook through the hole in the lug of S_1B_8 and bring the end of the hook to S_1B_9.

Step 3. Make a good tight connection on S_1B_9 and solder it.

Step 4. At S_1B_8, push back the insulation a little more so that enough wire is exposed to wrap once around the lug. Tighten this connection with your long-nose pliers and solder it. If necessary, push the insulation back toward the lug. Tie two knots in this lead.

JOB 8-5

To solder a lead to terminal S_2A_2.

Procedure.

Step 1. Cut off one 10-inch length of stranded hook-up wire. Push back 1/4 inch of insulation from each end twist each end and tin it slightly.

Step 2. Solder one end of this lead to S_2A_2. Make sure that the other connection to this lug is soldered too.

JOB 8-6

To connect the battery leads to the battery clips.

Procedure.

Step 1. Cut off 3-1/2 inches of stranded hook-up wire. Push back 1/4-inch of insulation from each end and tin it.

Step 2. Connect one end of this lead to the upper (positive) terminal of the small battery clip and solder the other end to upper (negative) terminal of the large battery clip, as shown in Fig. 8-7.

Step 3. Turn the RANGE switch of the meter to the 500 VDC position and place the meter face down alongside the meter box, as shown in Fig. 8-8*a*.

Step 4. Solder the lead with no knots that is connected to S_2A_2 to the lower (negative) terminal of the small battery clip.

Step 5. Solder the 8-inch lead connected to S_1B_8 (the one with the two knots) to the upper (positive) terminal of the small battery clip. Make sure that the lead already connected to this terminal is soldered also.

Step 6. Connect and solder the remaining 8-inch lead (the one with one knot in it) to

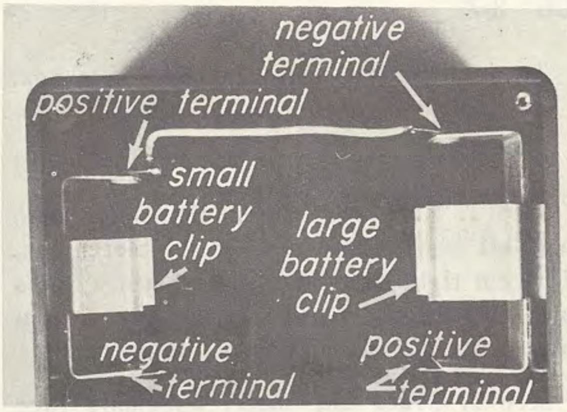
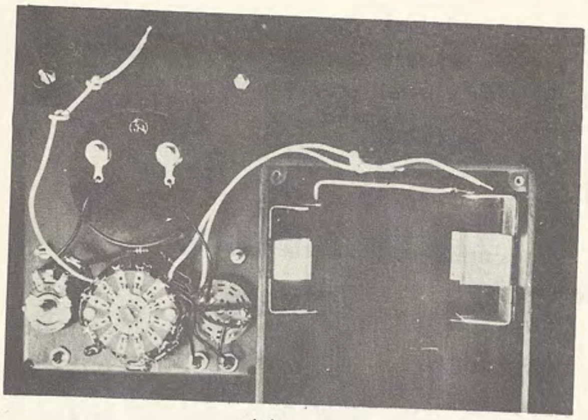
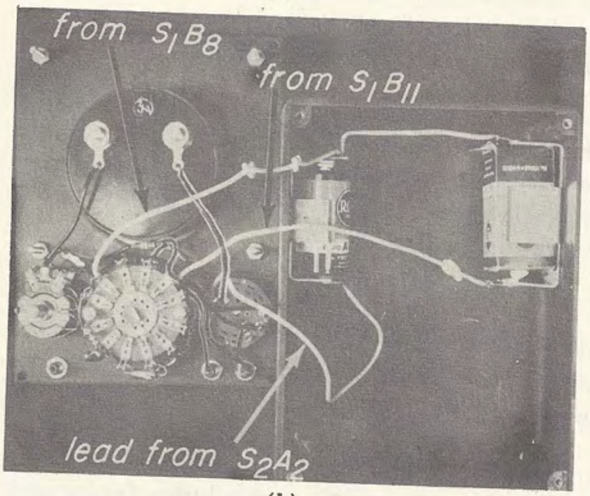


Fig. 8-7



(a)



(b)

Fig. 8-8

the lower (positive) terminal of the large battery clip.

Step 7. Place the 1.5-volt cell and the 6-volt battery in the clips, as shown in Fig. 8-8*b*.

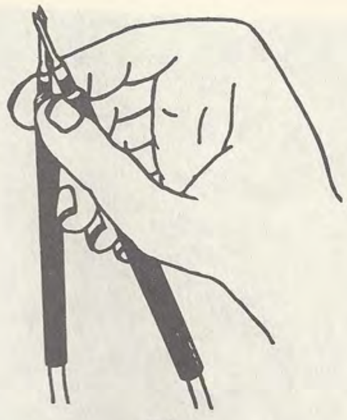
JOB 8-7

To replace the meter in the meter box.

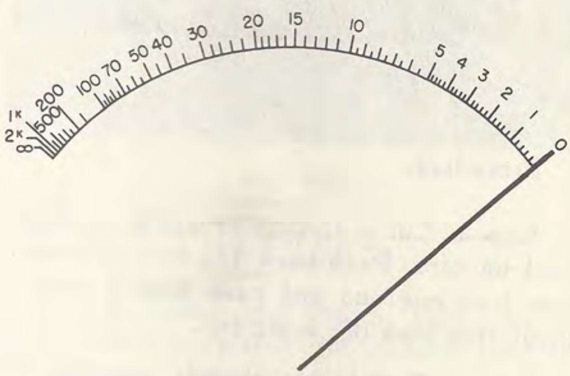
Procedure.

Step 1. Hold the meter assembly, with your left hand, face up over the meter box. With your right hand, dress the battery leads down toward the bottom of the box so that they do not get in the way of the switches.

Step 2. Place the meter assembly face up in the case and fasten the panel at the four corners with the four panel screws.



(a)



(b)

Fig. 8-9

JOB 8-8

To prepare the multimeter for use as an ohmmeter on the R x 1 scale.

Procedure.

Step 1. Turn the FUNCTION switch to the OHMS marker line.

Step 2. Turn the RANGE switch to the R x 1 marker line.

Step 3. Place the black test lead phone tip in the black (negative) pin jack and the positive test lead phone tip in the red (+) pin jack.

Step 4. Zero the meter. This is done by holding the tips of the positive and negative test prods together between your left thumb and forefinger, as shown in Fig. 8-9*a*, and adjusting the ZERO OHMS knob until the meter needle rests directly over the zero calibration line on the OHMS scale, as shown in Fig. 8-9*b*.

Your meter is now ready to measure resistance directly in ohms on the R x 1 range.

Caution: Before attempting to use the ohmmeter ranges of your multimeter, read and study carefully the instructions for the use of an ohmmeter given in Service Practices 7.

PART TWO

EQUIPMENT NEEDED

Multimeter

Soldering iron, cloth, and solder

Long-nose pliers

The resistor board assembled in Experiment Lesson 1

INFORMATION

Even though you have carefully studied the instructions for using an ohmmeter given in Service Practices 7, there are a few instructions that must be repeated here.

1. Never connect the ohmmeter ranges of your multimeter to any source of electric power, such as a dry cell, battery, generator, or your home or shop power lines.

2. Always be sure that all sources of electricity are disconnected from a piece of equipment before using your ohmmeter ranges.

3. For the most accurate readings, use the ohmmeter range that gives you a reading in the center path of the meter scale, as shown in Fig. 8-10. When measuring very-low or very-high resistance values, it is not always possible to get a reading in this center half of the scale.

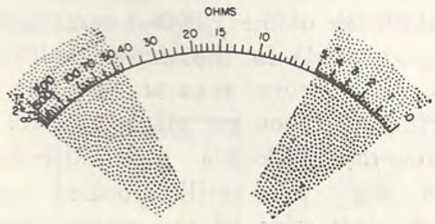


Fig. 8-10

4. For accurate readings, be sure that the meter is zeroed for the ohmmeter scale you intend using.

EXPERIMENT 8-1

To use the ohmmeter to measure the resistor breadboard.

Procedure.

Step 1. Your ohmmeter should be ready to measure resistance on the R x 1 range. Place one test prod at one end of the 100-ohm resistor and the other test prod at the other end of the same resistor. Read the value of resistance on the ohmmeter scale. The meter needle should come to rest near the 100-calibration line on the top (ohmmeter) scale. Because you are using the R x 1 scale, you multiply this reading by 1, which gives you a value of 100 ohms.

Step 2. In the same way, measure the resistance of the 220-ohm resistor. Record the value here:

220

Step 3. Measure the resistance of the 330-ohm resistor. Record the value here:

330

Step 4. Measure the resistance of the 1,000-ohm resistor, and record the value here:

1k

Step 5. Measure the resistance of the 10,000-ohm resistor and 100,000-ohm resistors. Note the position of the meter needle in each case, but do not record any value.

Discussion. In all the readings that you have just made, the needle should have come to rest at the left end of the meter dial. In the case of the first four resistors, the readings were probably close to the values shown by the color code. In the case of the last two resistors (10 k-ohm and 100 k-ohm), the meter needle hardly moved, and there was no way by which you could tell one resistance value from the other.

You have been told in this lesson and in Service Practices 7 that the ohmmeter is most accurate when the reading falls in the center half of the scale. None of the readings that you made fall in this portion of the scale. For this reason, you will next try the R x 100 range. Readings on this range are multiplied by 100.

Preparation. Turn the RANGE switch to the R x 100 marker line. Zero the meter by holding the tip of the test prods together as you adjust the ZERO OHMS knob until the meter needle is directly over the zero calibration line on the OHM scale.

Step 6. Measure the resistance of the 100-ohm resistor and record the value here:

120Ω

Step 7. Measure the resistance of the 220-ohm resistor and record the value here:

280Ω

Step 8. Measure the resistance of the 330-ohm resistor and record the value here:

420Ω

Step 9. Measure the resistance of the 1,000-ohm resistor and record the value here:

1160Ω

Step 10. Measure the resistance of the 10,000-ohm resistor and record the value here:

12,000

Step 11. Measure the resistance of the 100,000-ohm resistor and record the value here:

100,000+

Discussion. In the measurements just made, for the first three readings, the needle came to rest at the right-hand side of the meter dial. While you probably got better readings than you did on the R x 1 scale, they were still not in the center half of the scale. However, there are times when the measurements you make cannot fall in that part of the scale. In such cases, you use whichever scale gives you the better reading.

In the case of the 1,000-ohm resistor, the reading did fall in the center half of the scale, so a more accurate reading was possible. While you got slightly better readings for the 10 k-ohm and 100 k-ohm resistors, they were still crowded together near the left side of the scale. For that reason, you will now repeat these measurements on the R x 10 k range. On this range,

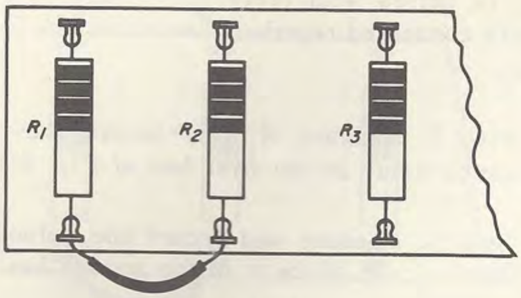


Fig. 8-11

all readings are multiplied by 10,000.

Preparation. Turn the RANGE switch to the R x 10 K marker line and zero adjust as before.

Step 12. Measure the resistance of each of the first 4 resistors (100-ohm, 220-ohm, 330-ohm and 1,000-ohm resistors). Do not record these values but notice the position of the meter needle in each case.

Step 13. Measure the resistance of the 10,000-ohm resistor and record it here:

10,000+

Step 14. Measure the resistance of the 100,000-ohm resistor and record it here:

100,500

Discussion. The four readings that you took in Step 12 were of very little value because they were all crowded together at the right-hand side of the scale. However, the readings that you got on the 10,000-ohm and 100,000-ohm resistors were in the center half of the scale. As a result, they were more accurate and more useful.

PART THREE

EQUIPMENT NEEDED

Same as for Part One

Short lengths of hook-up wire used on the breadboard in Experiment Lesson 7

INFORMATION

In the experiments in Part 2, you measured the values of individual resistors and learned how to use the three ranges of your ohmmeter. In Part 3, you will combine resistors in series and in parallel, measure the total resistance in each case, and compare your measurements with the resistance values found by figuring them according to the rules studied in Theory Lesson 8. In any figuring that you do in this part of the lesson, use only the measured value of resistance for each resistor and not the rated value shown by the color code. In this way, your figuring will come much closer to the measured value of each combination of resistors.

To connect resistors together on your resistor board, use the small pieces of bare tinned wire that you used in Experiment Lesson 7. If you have thrown these wires away, it will be necessary for you to cut new ones.

EXPERIMENT 8-2

To connect two resistors in series and to measure the total resistance.

Procedure.

Step 1. Connect the 100-ohm resistor R_1 in series with the 220-ohm resistor R_2, as shown in Fig. 8-11.

	resistance R_1		resistance R_2		total figured		total measured
Rx1 scale	105 Ω	+	280 Ω	=	385 Ω	=	400 Ω
Rx100 scale	120				400		

Fig. 8-12

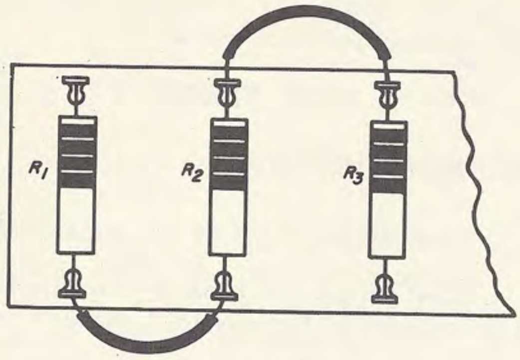


Fig. 8-13

Step 2. Measure, and record in the first box of Fig. 8-12, the resistance of R_1.

Step 3. Measure, and record in the second box of Fig. 8-12, the resistance of R_2.

Note: According to Theory Lesson 8, the total resistance of two or more resistors connected in series is equal to the sum of the individual resistances.

Step 4. Add the resistances of R_1 and R_2 together and put the answer in the third box of Fig. 8-12.

Step 5. With the ohmmeter, measure the resistance of R_1 and R_2 in series by placing one prod on each of the free ends of resistor R_1 and resistor R_2. Record this value in the fourth box of Fig. 8-12. If this has been done correctly, the value recorded in the third box should equal the value recorded in the fourth box.

EXPERIMENT 8-3

To connect three resistors in series and measure the total resistance and to compare this value with the calculated value.

Procedure.

Step 1. Connect the 330-ohm resistor, R_3, in series with resistors R_1 and R_2 (already connected together), as shown in Fig. 8-13.

Step 2. Measure R_1 and record the resistance value in the first box of Fig. 8-14.

Step 3. Measure and record the value of resistor R_2 and place it in the second box of Fig. 8-14.

Step 4. Measure and record the value of R_3 in the third box of Fig. 8-14.

Step 5. Add these three values together and record the sum in the fourth box of Fig. 8-14.

Step 6. Measure the total resistance of R_1, R_2, and R_3 in series by placing one prod on the free end of R_1 and the other on the free end of R_3. Record this value in the fifth box of Fig. 8-14. The value of resistance recorded in the fourth box should equal the value of resistance recorded in the fifth box. They may vary a little, of course.

EXPERIMENT 8-4

To connect two resistors in parallel, to measure their resistance, and to compare this value with the calculated value.

Procedure.

Step 1. Disconnect from R_3 the lead that connects it to R_2. Then connect the free end of this lead to R_1, as shown in Fig. 8-15.

Step 2. Record, in the first box of Fig. 8-16, the resistance of R_1, as you measured it in Experiment 8-3.

Step 3. Record, in the second box of Fig. 8-16, the resistance of R_2 as you measured it in Experiment 8-3.

resistance R_1		resistance R_2		resistance R_3		total figured	total measured
120 Ω	+	280 Ω	+	420 Ω	=	820 Ω	780 Ω

Rx1 Scale 105 805

Fig. 8-14

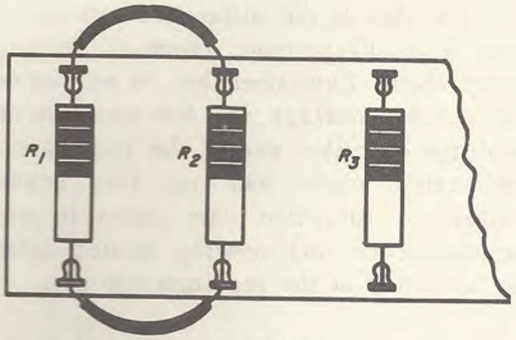


Fig. 8-15

Note: According to Theory Lesson 8, the total resistance of any two resistors connected in parallel is equal to their product divided by their sum.

Step 4. Calculate the value of R_1 and R_2 in parallel in the way described above. Record this value in the third box of Fig. 8-16.

Step 5. Measure the value of the resistance of R_1 and R_2 in parallel by placing one prod on one end of R_1 and the other prod on the other end of R_1. Naturally, you could also measure this resistance by placing one prod on one end of R_2 and the other prod on the other end of R_2. In either case, you would get the same answer. Record this measurement in the fourth box of Fig. 8-16. The value of the resistance in the third box should equal that in the fourth box. If there is a great difference between the two values, check the figuring you did to get the calculated value.

76+
385 | 29400
2695
2450
2310

EXPERIMENT 8-5

To connect three resistors in parallel, to to measure the total resistance, and to compare the value with the calculated value.

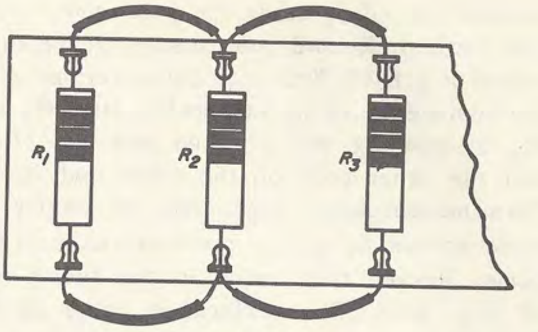


Fig. 8-17

Procedure.

Step 1. Connect resistor R_3 in parallel with resistors R_1 and R_2, as shown in Fig. 8-17.

Note When three resistors are connected in parallel, the total resistance may be calculated by using the product-over-the-sum method. Just do the work in steps. For example, to find the total resistance of R_1, R_2, and R_3 in parallel, we may first calculate the resistance of two of them in parallel and use this calculated value in parallel with the third resistor. You have already calculated the resistance of R_1 and R_2 in parallel, so record this value in the first box of Fig. 8-18.

Step 2. Record, in box 2 of Fig. 8-18, the measured value of resistance of R_3 as found in Experiment 8-3.

Step 3. Calculate the total resistance of the combination of the resistance in the first box in parallel with the resistance in the second box in parallel with the resistance in the

resistance R_1 120 Ω	resistance R_2 280 Ω
product/sum 84 Ω	parallel resistance measured 72 Ω

Rx1 - 105

76+ → 72 Ω

400
280
120
5600
280
33600

84
4 | 336

Fig. 8-16

parallel resistance R_1 and R_2 76 Ω	resistance R_3 420 Ω
product/sum 64+ Ω	parallel resistance measured 60 Ω

420
76
2520
2940
31920

64+
496 | 31920
2976
2160

Fig. 8-18

second box (R_3), using the product-over-the-sum method. Record your answer in the third box of Fig. 8-18. With your ohmmeter, measure the resistance of R_1 in parallel with R_2 and R_3, by placing one prod on one end of R_1 and the other prod on the other end of R_1. This measurement might just as easily be made across R_2 or R_3; the resistance is the same. Record this value in the fourth box of Fig. 8-18. The resistance value in the third box should equal that of the fourth box. If there is a great difference between these values, check your calculation.

Discussion. Let's see what you learned in the second and third parts of this Experiment Lesson. In Experiment 8-2, you found that the resistance of R_1 and R_2 in series, as measured, is equal to R_1 added to R_2.

In Experiment 8-3, you found that R_1, R_2, and R_3 in series equal, when measured, $R_1 + R_2 + R_3$. You might have gone on adding resistors in series only to find that the total resistance is still equal to the sum of the individual resistors. No doubt you found some places where the figures were not exactly equal, even though they were supposed to be. If the difference was not more than 5 to 10 percent, there is nothing to worry about. Remember that, in an ohmmeter, the center readings are the most accurate; readings on either end of the scale are only reasonably close and not very accurate. Remember, too, that care taken in making measurements and reading scales adds to the accuracy of the readings you get.

In Experiment 8-4, you found that the measured resistance of two resistors connected in parallel was about equal to the calculated value. You probably found that the product of two resistors divided by their sum is a pretty good way to find the total resistance of two resistors in parallel and you probably found that this method works equally well when there are three or more resistors in parallel. What is more important is that you have proved in this, and in the last lesson, that many of the things you learned in the theory lessons are true – because you are actually able to measure and see for yourself. If you found the last two lessons interesting, you will find the following Experiment Lessons even more interesting. What is more, you will soon know much more about the circuits of your multimeter.