Study Group 2

ELECTRONIC FUNDAMENTALS

Theory Lesson 3:	How to Use Color Codes
Experiment Lesson 3:	Starting the Multimeter Assembly
Theory Lesson 4:	Electron Theory and Current
Experiment Lesson 4:	Electrostatic Experiments

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

New York, N. Y.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 3

HOW TO USE COLOR CODES

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

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

Theory Lesson 3

INTRODUCTION

In the early 1920's, when radio broadcasting was very new, most radio receivers were made at home. The parts that went into them were very difficult to obtain. In fact, many of them were hand-made by boys and young men who were anxious to be among the first to own one of the newfangled wireless sets. In assembling one of these early radios, many hours were spent winding coils on large wooden coil forms or empty oatmeal boxes. As a result, some of the coils were actually larger than some radio receivers are today (see Fig. 3-1). However, some of the parts, such as resistors and capacitors, had to be bought, and there were very few stores that sold them.

In some cases, the parts were marked with the value of the resistance or capacity. In other cases, you just took the salesman's word that he was giving you the value that you had asked for. For example, the capacity of a mica capacitor might be painted or stamped on it, or it might be pressed into the bakelite case, if it had one. When it came to resistors, sometimes the only way you could tell the value of a resistor was by the value marked on the box that it came out of. If someone had returned a resistor to the wrong box, the resistor you bought might be entirely different in value than the resistor you wanted.

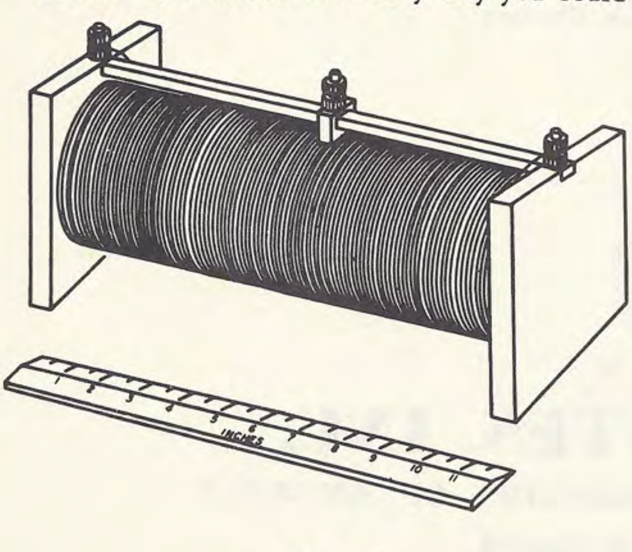


Fig. 3-1

In the few factories where radio receivers were made in those days, the problem of knowing one part from another was even greater than it was for the individual set builder. In a parts stock room, one box might contain several hundred resistors of a certain value. The box next to it might contain resistors of an entirely different value. If they got mixed up, as they sometimes did, there was no way in which anyone could tell the difference, except by measuring them with meters, which at that time were very scarce. One manufacturer developed a special color code for making resistors used in his radios, but only that manufacturer and some of his employees knew the code. The result was that when a radio serviceman fixed a radio with these coded resistors in it, he could not read resistor values unless he was an employee of the manufacturer.

3-1. COLOR CODE ADOPTED

However, most resistors and capacitors were not coded. With one resistor looking very much like the next one, you can well understand how mistakes were made and time was lost in making the necessary changes when wrong resistors were wired into new radio receivers. So, after some time, certain manufacturers started an organization that they called the Radio Manufacturers Association, which is now known as the Radio-Electronics-Television Manufacturers Association (RETMA, for short). Among other things, they decided to set up ways to prevent such mistakes. They devised a color code for marking resistors and capacitors for easy identification, and mistakes became less frequent.

Today most carbon composition and ceramic-cased wire-wound resistors are color coded. In addition, some paper-dielectric capacitors, all mica-dielectric capacitors, and most audio-frequency and radio-frequency transformers are color coded. Even the wiring of some radios and other electronic devices is marked with a color code, so that the various circuits may be identified by the color of wire used. More and more, it is important that people in radio be familiar with these codes. In any working day, a serviceman uses his knowledge of color codes many times. For example, color codes help him to identify resistors and capacitors in his stock, to identify the leads of the different types of transformers that are in a receiver, and to locate parts and trace circuits. When making his purchases of replacement resistors and capacitors, he may save a repeat trip to the distributor by checking the value of the parts he buys before he leaves the salesroom.

While some servicemen sometimes make use of color-code cards, color-code wheels, and other similar devices to identify the values of resistors and capacitors, this method is a time waster. Each time a repairman finds a resistor or capacitor that he wants to identify, he has to refer to his card or color-code device to find the value of the part. A serviceman who relies on such aids is lost when he forgets to take his color-code card on service calls away from his shop. On the other hand, if he *knows* the color codes, he just can't leave them behind, so he always has the answers when he needs them. The man who really knows his color code works much more surely without constant reference to cards, so he makes a good impression on his customers. Customers realize that such a man knows what he is doing. The man who often refers to color cards and other notes gives the customer the impression that he is weak in his radio knowledge. For these and other reasons, it is very important that you learn the basic color code and how it is applied to coded parts.

In this lesson, most of the normally used color codes are included. These codes are brought together in this one lesson so that they will be available to you for reference, now and in the future. For that reason, it is suggested that, when you are through with this lesson and have learned the basic code and how it is used, you bind this lesson with your Service Practices booklets. Then you will have the color codes always available for ready reference.

3-2. THE BASIC COLOR CODE

The basic color code consists of ten colors. Each of these colors, as shown in Table A, represents a digit from 0 through 9. Before you can learn any code, it is necessary that you learn what digit each of these colors stands for. The quickest and easiest way to learn this basic color series is by rote—which means by memorizing the colors in order. By repeating them over and over, as perhaps you learned your alphabet, you will find that you should know them in 15 to 30 minutes. When you can repeat them—black, brown, red, orange, yellow, green, blue, violet, gray, white, in that order, without hesitation—read on and see how these colors are applied to the first color code, which is the color code for identifying resistors.

TABLE A – BASIC COLOR CODE

Color	*Digit*
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

3-3. RESISTORS

Just as it is possible to drive an automobile, operate an adding machine, or use an electric shaver without knowing the theory behind them, so it is possible to use resistors without knowing what they do. You will learn about resistors in the next few lessons, but, for the time being, we are going to talk about resistors just as radio parts without going into the theory behind them.

In Service Practices 1, How To Identify Radio Parts, you saw pictures of typical resistors. In radio and TV receivers, carbon resistors are used most often and they look like those shown in Fig. 3-2. Figure 3-2*a* shows an *axial-lead resistor* (one where the leads are in line with the axis of the resistor). Most of the fixed carbon composition resistors now being made are of this type. Figure 3-2*b* shows a resistor with *radial leads* (each lead radiates out from the end like a spoke of a wheel does from its hub). Although practically no resistors of this type are being made any more, many millions of receivers contain them. No doubt you will find many of them in your service work, so it is necessary for you to know how to identify them when you see them. For that reason, they have been included in this lesson.

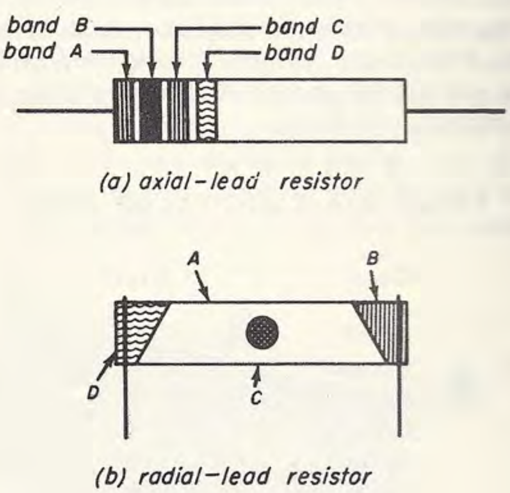


Fig. 3-2

If you will carefully examine the illustration of the axial-lead resistor, you will see that there are four color-bands used to identify the resistor value. The first of these, marked Band *A*, stands for the first *significant figure.* Just what is a significant figure? You will meet this term many times in this course, so let's stop a moment and see what it means.

Significant Figures. Significant figures are those that are known to be correct by direct measurement or meaningful calculation. For example, suppose a motorist does 3 miles in 7 minutes. His rate of speed is 3 miles divided by 7/60 hours. If the long division is carried on and on, an answer of 25.7142 miles per hour can be obtained. But the last four digits of the answer are not justified – the original measurements are not this accurate. The result should contain only two significant figures, 26 miles per hour. The answer is *rounded* off to the next higher number when the next digit is 5 or more; the next is dropped if it is 4 or less. Thus, if our answer had been 25.3, it would be rounded off to 25 miles per hour.

The resistor color code is capable of giving the values of resistors correct to 2 significant figures. Thus, a resistor whose actual value might be 27,374 ohms is labeled by the color code as a 27,000-ohm resistor. In this case, the three zeroes are not significant figures. They certainly are important, because they tell the order of size of the resistor. It is 27,000 ohms, not 270 ohms or 270,000 ohms. But the zeroes do not really tell the true value of the digit that should be in the third, fourth, and fifth position of the number, and in technical language, are not significant figures. If the resistor were actually 27,000 ohms, it would be written 27,000.0 ohms to show this fact.

A resistor value that is given as 1,000 ohms contains two significant figures, because this number tells us that it is closer to 1,000 than it is to 990 or 1,100 ohms. However, the last two zeroes in this case are not significant, because we have no way of knowing if the true value is really 1,000 ohms, or 1,012 ohms, or 998 ohms. The last two zeroes only fix the order of size of the resistor.

Resistor Color Code. We have already pointed out that band *A* stands for the first significant figure. Band *B* stands for the second significant figure. Band *C* is called the *multiplier;* it stands for the number of tens by which you must multiply the two significant figures you read on the first two bands. Stated another way, the multiplier band tells you how many zeros you must add to the significant figure to get the correct value. Band *D*, the fourth band, stands for the *tolerance* of the resistor. By tolerance, we mean the amount that a part may vary from the rated value that is indicated on the first three bands.

It is necessary to provide a tolerance indication because it is very difficult to make carbon composition resistors of an exact value. Usually the value of a resistor, as it is marked on the first three bands, is a compromise value between the highest and the lowest possible values that the resistor might have. For example, a resistor might be marked as rated for 1,000 ohms. Reading the tolerance band, we learn that the actual value of the resistor may be as high as 1,200 ohms or as low as 800 ohms. Because tolerance is usually expressed as a percent of the rated value, we speak of this resistor as having a tolerance of ±20% (plus or minus twenty percent). In this way, we are saying that the resistor will have a value that is somewhere between the rated value plus 20% and the rated value minus 20%. Resistors for use in radio and TV receivers are classified in three *tolerance* groups: those that vary as much as 20% above or below the rated value, those that vary as much as 10% above or below the rated value, and those that vary as much as 5% above or below the rated value. Very few resistors are now made with a 20% tolerance, although they may be found in many older radio receivers. Resistors having a tolerance of less than 5% have their value in ohms and tolerance in percent imprinted on the body. These are called precision resistors. To indicate tolerance, we use two additional colors: gold and silver. If the tolerance of a resistor is ±5%, Band *D* is gold. If the tolerance is ±10%, Band *D* is silver. If the tolerance is ±20%, there isn't any fourth band. Thus, resistors with only three color bands have a tolerance of ±20%. When reading resistors without tolerance bands, remember to start with the band nearest the end of the body.

Examine Table B. It shows what each color on the four color bands found on carbon composition resistors and ceramic-cased wirewound resistors stands for. For example, suppose a resistor has four color bands as follows: brown, black, brown, silver, as in Fig. 3-3. Looking at the chart, you will find that the brown of Band *A* stands for the digit 1, and the black of Band *B* stands for zero (0). The first two figures, then, are *1* and *0*. The brown of Band *C* stands for a multiplier of 10. You learned in school that to multiply a number by 10 you just add a zero to the

TABLE B – RETMA CARBON COMPOSITION RESISTOR CODE

Also Military Standards of Defense Department.

Color	Band A–First Significant Figure	Band B–Second Significant Figure	Band C – Multiplier: Multiplier	Band C – Multiplier: Number of Zeros Added	Band D – Tolerance
Black	0	0	x1	Add no zeros	
Brown	1	1	x10	Add 0	
Red	2	2	x100	Add 00	
Orange	3	3	x1,000	Add 000	
Yellow	4	4	x10,000	Add 0000	
Green	5	5	x100,000	Add 00000	
Blue	6	6	x1,000,000	Add 000000	
Violet	7	7	x10,000,000	Add 0000000	
Gray	8	8	x100,000,000	Add 00000000	
White	9	9	x1,000,000,000	Add 000000000	
Gold			x 0.1		±5%
Silver			x 0.01		±10%
No Color					±20%

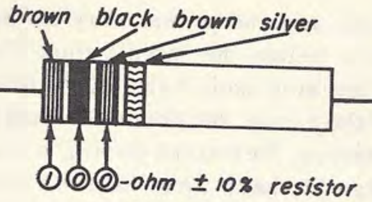


Fig. 3-3

number. So in this case, we take the two significant figures we already have, 10, and multiply them by the multiplier, 10. We do this by adding zero to the two significant figures and we get 100. The unit of resistance value is the *ohm*, so the value of the resistor is 100 ohms. Band *D* is silver, which means that the tolerance is plus or minus 10%. Therefore, the color code identifies a resistor of 100 ohms with a tolerance of plus or minus 10%; therefore the resistance has a value between 100 *plus* 10% or 110, or 100 *minus* 10% or 90.

Before we go on to another resistance value, let's take a moment and examine the column under Band C – Multiplier. You have noted that black stands for 0 as a significant figure in bands A and B, and that brown stands for 1, red stands for 2, and so forth.

The same idea is carried out in the third band, because the multiplier *black* shows that we multiply the first two figures by 1. So, if a resistor is coded brown, black, gold, the first digit would be 1, the second digit would be zero, and because the third band is black, we would multiply the first two digits by 1 (no zeros are added). As a result, we would find the resistor value to be 10 ohms plus or minus 5%. A thousand-ohm resistor on the other hand, as shown in Fig. 3-4*a*, is coded brown, black, red, and whatever tolerance band is suitable. The red multiplier shows that we multiply the first two figures by 100, which just means adding two zeros to the first two digits. An orange multiplier means adding three zeros; yellow, four zeros; green, five zeros; and so on. A resistor coded red, red, and red, as in Fig. 3-4*b*, is decoded as 2,200 ohms and, because there is no tolerance band, it has a tolerance of plus or minus 20%. A resistor of 47,000 ohms plus or minus 5% would have a yellow Band *A*, violet Band *B*, orange Band *C*, and a gold Band *D*, as shown in Fig. 3-4*c*.

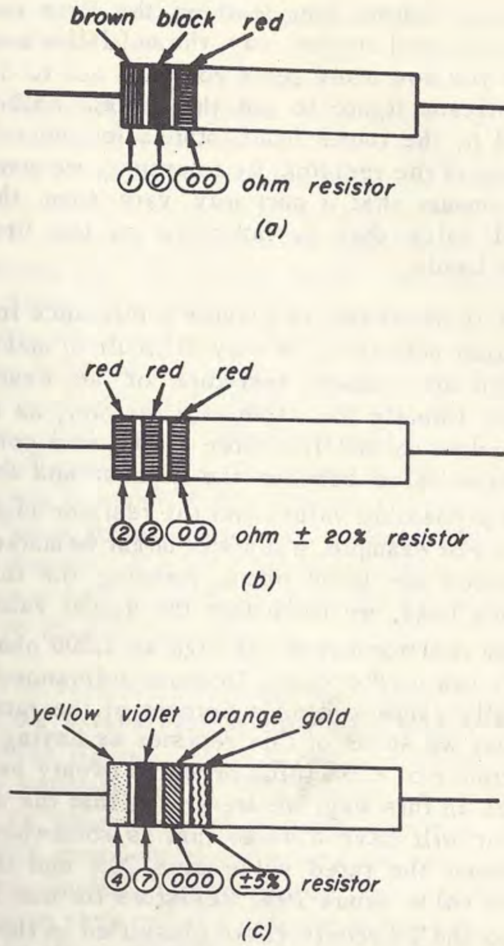


Fig. 3-4

Up to now we have discussed only values of resistance of 10 ohms or over. What happens when the color code is applied to lower resistor values? Let's see. If the resistance is one ohm, we cannot code it brown, black, black, because that is the code for 10 ohms (black as a significant figure is zero). To encode (to put into code) a resistor of one ohm, the first significant figure is one (brown) and the second significant figure is zero (black) as shown in Fig. 3-5*a*. *Gold* is used as a multiplier in the third band. On the chart, at the bottom of the Band C – Multiplier column, you will find that gold is a decimal multiplier equal to 0.1 (1/10) and that silver is a decimal multipler equal to 0.01 (1/100). When gold appears in the *third* band, it does not indicate tolerance, but that the figure obtained from the first two bands is to be multiplied by 0.1. Now, on a resistor of 0.1 ohm, the first color band would be brown, the second one would be black, and

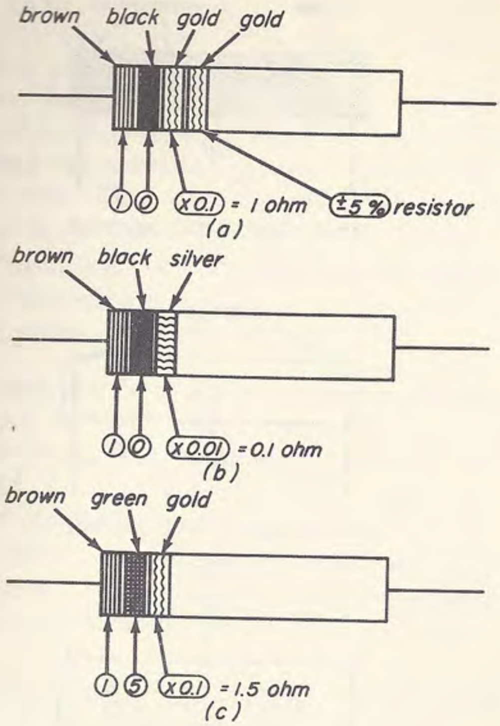


Fig. 3-5

the multiplier band would be silver, as in Fig. 3-5*b*. This would be decoded by multiplying 10 by 0.01 and getting a resistor value of 0.1 ohm. In much the same way a resistor coded brown, green, and gold would be decoded: 1, 5, and a multiplier of 0.1, as in Fig. 3-5*c*. So multiplying 15 by 0.1, the value of resistance is found to be 1.5 ohms.

Wirewound Resistor Code. The same basic code that is used on carbon composition resistors is also used to indentify low power (2 watts or less) wirewound resistors. For that reason, it is not possible to tell the difference between these resistors by looking at color alone. Yet, it is necessary to be able to tell a carbon composition resistor from a wirewound resistor, because sometimes only one or the other can be used in a circuit. It is done in this manner: Carbon composition resistor color bands are of equal width; Band *A*, in wirewound resistors, as shown in Fig. 3-6, is *twice the width* of the other bands. So whenever you see that the first band of a resistor is wider than the other bands, you will know that the resistor is wirewound.

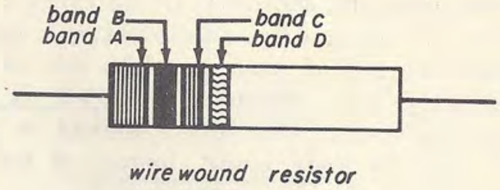


Fig. 3-6

Uninsulated resistors (excepting radial lead resistors) have black bodies. Insulated resistors commonly have tan bodies. Both types have colored bands to indicate their values.

Radial-Lead Resistor Code. Up to this point little mention has been made of the radial-lead resistor, which was shown in Fig. 3-2*b*. Changes in manufacturing methods have made radial-lead resistors out of date, and they are no longer made by leading manufacturers. However, there are so many of them in radios all over the country that it is necessary for you to know how the color code applies to them. Instead of being arranged in three or four color bands, the colors are placed and read in this order: *A*– body color, which stands for the first significant figure; *B*– end color, which stands for the second significant figure; *C*– dot color, which stands for the multiplier; and *D*– tolerance color (at the other end), which stands for the percentage of tolerance. For example, as shown in Fig. 3-7, a 100-ohm resistor with a tolerance of 10% would have a brown body (one), a black end color (zero), a brown dot (add one zero), and a silver tolerance end (10%). It is not possible to mistake the ends, because gold or silver can never stand for a significant figure. If there is no tolerance color (no gold or silver end), the tolerance is ±20%.

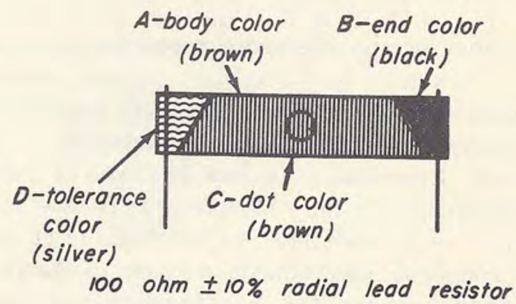


Fig. 3-7

Sometimes the multiplier is represented by a band in the middle, instead of by a dot. The same method of reading colors that is used for axial lead resistors, Fig. 3-4, is used for radial-lead resistors. Instead of Band *A*, read the body color; instead of Band *B*, read the end color; instead of Band *C*, read the middle dot or band; and instead of Band *D*, read the tolerance end.

There are some special cases that come up in reading the color code on radial-lead resistors. This is because the body of the resistor and one of the color-code markings on the body may be the same color. Some resistors have no end markings, others have no middle dot or band, and still others have no markings other than a body color. These resistors are properly color coded, even though they seem puzzling at first glance. Where there is no separate end color, the end color is taken to be the same as the body color. Where there is no separate middle dot or band color, it, too, is the same as the body color. For example, a resistor with an orange body, with one end the same color, the other end silver, and with a red middle dot, as in Fig. 3-8*a*, would be decoded 3 (orange), 3 (orange), add two zeros (red), and a tolerance of plus or minus 10%. Because gold or silver can never be a significant figure, we know that the end marked with silver must stand for the tolerance. On the other hand, a resistor with an orange body with a gold middle dot and no other markings, as in Fig. 3-8*b*, would be decoded 3 (orange), 3 (orange), and multiplied by 0.1 (gold). This would identify a resistor of 3.3 ohms with a tolerance of plus or minus 20%. In much the same way, a resistor that is completely red, as in Fig. 3-8*c*, would be decoded 2 (red), 2 (red), add two zeros (red), and stand for a resistor of 2,200 ohms plus or minus 20%.

Most of the resistors found in radio and TV sets may be identified by this resistor color code, which has become part of the Military Standards of the Department of Defense. Remember, no law requires a manufacturer to use the resistor code or any other color code exactly as written. For that reason, you may find a resistor difficult to decode because the manufacturer took some liberties with the code. With a little thought,

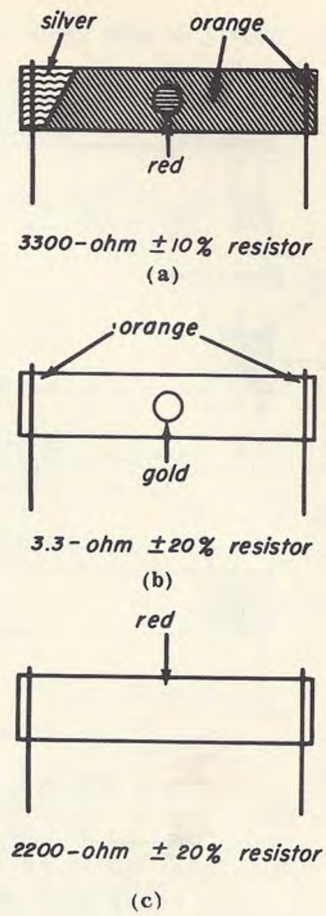


Fig. 3-8

you will probably be able to puzzle out the value even in these special cases.

The resistor code is the color code that you will probably use most often in your work. You will save yourself a lot of time and work much more efficiently if you will learn this code by heart. The test that you will find at the end of this lesson includes many questions based on the resistor code. When you have completed this lesson, take the test and see how much you really know about color codes.

3-4. CAPACITOR CODES

Mica Dielectric Capacitor Code. The next code that you should know about is the color code for mica dielectric capacitors. At this time, it is not necessary that you learn this code by heart; but you should learn how to use it. Actually there are and there have been many forms of the mica capacitor code. Some of them are outdated and were used so seldom that it does not pay to learn them. For this reason, they are not included in this lesson. There are, however, four mica codes which you should know something about. They are: the old RMA (Radio Manufacturers Association) 3-dot, the old RMA 6-dot, the new RETMA (Radio Electronic Television Manufacturers Association), and the Military Standards codes.

Fortunately, these codes are basically the same and use the same color system as the resistor code. The easiest to learn is the old RMA 3-dot color code. While this code and the old RMA 6-dot code are almost outdated, there are so many capacitors that were marked by these codes that you should know how to identify them.

The Old RMA 3-Dot Code. Figure 3-9 shows three capacitors that are marked under the 3-dot code. In using this code, it is important to know in which order the color markings on the capacitors are to be read. In the 3-dot code, they are always read from left to right. The only difficulty might be in trying to find out which way to hold the capacitor while reading the code. Two of the capacitors shown have arrows. When the capacitor is held so that the arrows point from left to right, it is in the proper position for reading. If the arrow points from right to left, turn the capacitor half way around, so that the arrow points from left to right, before reading. In the third capacitor, there is no arrow. In this case, the capacitor is held so that the manufacturer's name is right side up so that it can be read. When the capacitor is in this position, the 3-dots are read from left to right as on the other capacitors. The unit of capacity is the farad. However, the capacity of mica dielectric capacitors is given in micromicrofarads (sometimes abbreviated mmf, sometimes $\mu\mu f$), whenever the color code is used.

The Old RMA 3-dot color code is applied in this manner: The first dot (the one on the left) stands for the first significant figure, the middle dot stands for the second significant figure, and the third dot (the one on the right) is the multiplier and stands for the number of zeros added to the first two digits. For example, a capacitor that has red for the first dot, green for the second dot, and brown for the third dot, as in Fig. 3-10, would be decoded as follows: 2 (red), 5 (green), add zero (brown). This stands for a capacitor of 250 $\mu\mu f$. Figure 3-11 and Table C show the code applied to the old RMA 3-dot and 6-dot coded capacitors. The first two columns and the multiplier column apply to the 3-dot code. All six columns apply to the 6-dot code.

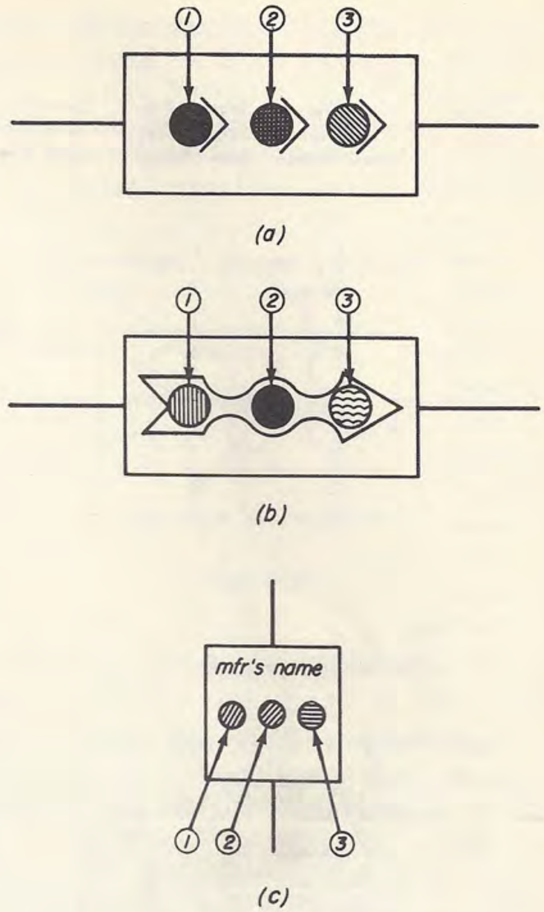
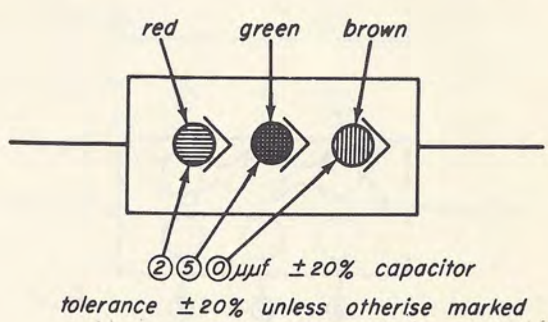


Fig. 3-9



voltage 500 wv unless otherwise marked

Fig. 3-10

TABLE C – OLD RMA MICA-DIELECTRIC CAPACITOR CODE

Color	First Dot– First Significant Figure	Second Dot– Second Significant Figure	Third Dot– Third Significant Figure	[1]Fourth Dot – Multiplier: Multiplier	Number of Zeros Added	Fifth Dot– Tolerance	Sixth Dot– Voltage Rating
Black	0	0	0	x1	Add no 0		
Brown	1	1	1	x10	Add 0	±1%	100 wv
Red	2	2	2	x100	Add 00	±2%	200 wv
Orange	3	3	3	x1,000	Add 000	±3%	300 wv
Yellow	4	4	4	x10,000	Add 0000	±4%	400 wv
Green	5	5	5			±5%	500 wv
Blue	6	6	6			±6%	600 wv
Violet	7	7	7			±7%	700 wv
Gray	8	8	8			±8%	800 wv
White	9	9	9			±9%	900 wv
Gold				x 0.1		±5%	1000 wv
Silver				x 0.01		±10%	2000 wv
No Color						±20%	500 wv

[1]Third dot in the 3-dot code.

20% if no color   all 500 wv
5% gold
10% Silver

The 3-dot code is very similar to the resistor code given earlier in the lesson. Some manufacturers add a dot or splash of silver or gold on the body of the capacitor to indicate tolerance. When this is done, gold stands for plus or minus 5%, and silver for plus or minus 10%, as in the case of the resistor color code. When only the 3 dots are given, the tolerance is plus or minus 20%.

The Old RMA 6-Dot Code. Where the old RMA 6-dot code, shown in Fig. 3-12, is used, the manufacturer marks the capacitor with an arrow or his name to show how to hold the capacitor when reading the code. When there are 6-dots and the capacitor is held in the proper manner, the code is read from left to right on the *top row* of dots and from right to left on the *bottom row* of dots. (We say that it is read *clockwise* because we read in the direction that clock hands move.) The first three dots (on the top line) stand for the first three significant figures. The first dot stands for the first significant figure, the second dot stands for the second significant figure, the third dot stands for the third significant figure, the fourth dot (the one in the lower right-hand corner) stands for the multiplier (the number of zeros to be added), the fifth dot stands for the tolerance, and the sixth dot (in the lower left-hand corner) stands for the voltage rating. This last rating shows how much of

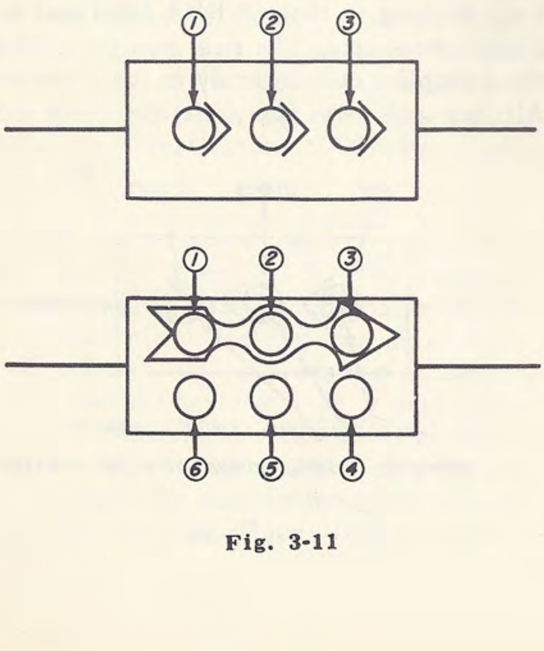


Fig. 3-11

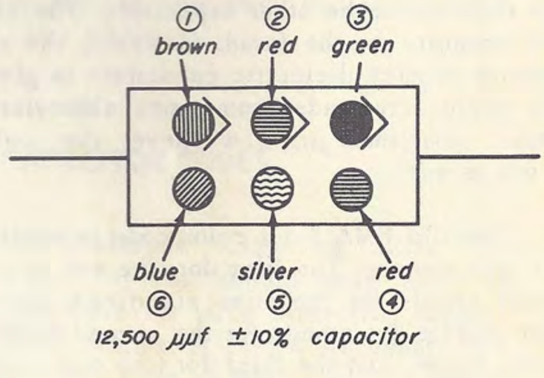


Fig. 3-12

what can be called electrical pressure may be connected across the capacitor. It is sometimes called the *working voltage,* abbreviated *wv.* In your later studies of capacitors, you will find that this is an important factor.

Let's take an example and see how this code works. A capacitor of 12,500 μμf, with a tolerance of plus or minus 10%, and a voltage rating of 600 volts, would be coded as follows: the first significant figure (1) would be represented by brown, the second significant figure (2) would be represented by red, the third significant figure (5) would be represented by green, the two zeros would be represented by red in the fourth dot, the tolerance plus or minus 10% by silver in the fifth dot, and the voltage rating by blue in the sixth dot.

While the old RMA mica capacitor codes are very much like the resistor color code, there are some differences that you must know about. Look carefully at the fifth (tolerance) column of Table C and you will see that each color, with the exception of black, represents a tolerance. Either gold or green could be used to stand for a tolerance of plus or minus 5%. Under this old code, it was possible to show a tolerance of plus or minus 1%. In the sixth column (voltage rating), you will find that every color except black represents a voltage rating, with brown standing for 100 volts, at the top of the list, and with gold standing for 1,000 volts, and silver standing for 2,000 volts near the bottom of the list. Where there is no color shown in the sixth dot, the voltage rating is 500 volts, which, by the way, is the voltage rating of all 3-dot capacitors unless otherwise marked.

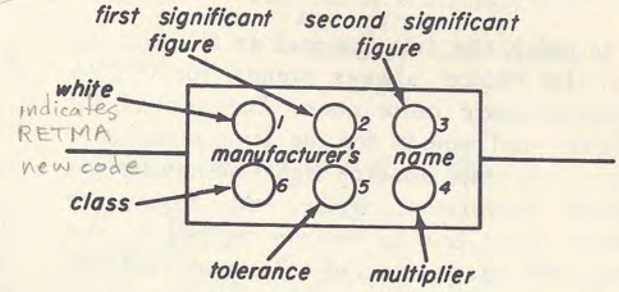


Fig. 3-13

RETMA Mica-Dielectric Code. If you examine Fig. 3-13 and Table D, you will find the present RETMA mica-dielectric capacitor code. You will note that the code uses six dots just like the old RMA 6-dot code. However, there are two important changes that make this code different from the old code. The 6 dots are read in the same order as the old code, but the first dot no longer stands for a significant figure. Instead, it is always white, which is to let you know that the capacitor uses the RETMA code. This is done because the Armed Forces use a somewhat different code, which might be confused with this one. The other change

TABLE D – RETMA MICA-DIELECTRIC CAPACITOR CODE

FIRST DOT WHITE ON ALL

Color	*Second Dot– First Signif-icant Figure*	*Third Dot– Second Signif-icant Figure*	*Fourth Dot – Multiplier*		*Fifth Dot – Tolerance*	*6th Dot– Class*
			Multiplier	*Number of Zeros Added*		
Black	0	0	x1	Add no 0	±20%	A
Brown	1	1	x10	Add 0		B
Red	2	2	x100	Add 00	±2%	C
Orange	3	3	x1,000	Add 000	±3%	D
Yellow	4	4	x10,000	Add 0000		E
Green	5	5			±5%	
Blue	6	6				
Violet	7	7				
Gray	8	8				
White	9	9				I
Gold			x0.1			J
Silver			x0.01		±10%	

affects the sixth dot, which no longer stands for a voltage rating but stands for a new *class* rating. The working voltage rating of mica capacitors is not given by the RETMA or military codes. For radio work, it may be assumed that most mica capacitors have a voltage rating of at least 500 volts d.c.

In order, the dots are read as follows: the first dot (white) always stands for RETMA mica-dielectric color code. The second dot (middle top) stands for the first significant figure, the third dot (top right) stands for the second significant figure, the fourth dot (lower right) stands for the multiplier, the fifth dot stands for the tolerance, and the sixth dot stands for the class of capacitor. For example, a capacitor coded as follows: white, red, green, brown, green, and brown, would be decoded as follows: RETMA coded mica-electric capacitor (white), 2 (red), 5 (green), add one zero (brown), plus or minus 5% tolerance (green), and Class *B* (brown). This would show a 250-$\mu\mu$f, plus or minus 5%, Class *B* mica-dielectric capacitor. If you examine the tolerance column of Table D, you will find tolerances of 2, 3, 5, 10, and 20%. Note that a tolerance of plus or minus 5% is represented by green instead of gold, and that plus or minus 20% is represented by black instead of by no color at all.

The sixth dot, which refers to the manufacturer's classification, includes many factors that do not enter into our work.

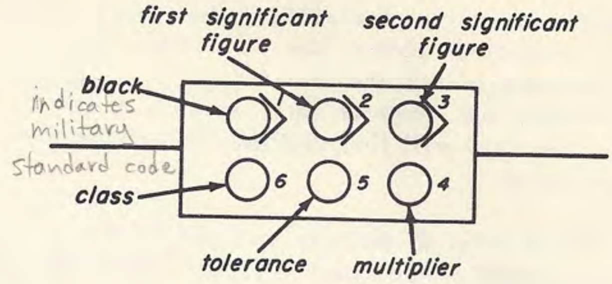


Fig. 3-14

Military Standard Mica-Dielectric Capacitor Color Code. Look at Fig. 3-14 and Table E. The Military Standard Color Code for mica capacitors looks very much like the code just discussed. It has, however, some differences which make it important for us to examine it separately. It is read in the same way that the RETMA mica code is read. However, the first dot (in the upper left-hand corner) is always black instead of white to indicate the Miltary Standard Color Code. A black dot in this position never stands for zero in any code. As in the RETMA color code, the second dot stands for the first significant figure, the third dot stands for the second significant figure, the fourth dot stands for the multiplier, the fifth dot stands for the tolerance, and the sixth dot stands for the class. It differs from the RETMA code in that there is no tolerance for plus or minus 3% and that plus or minus 5% is gold instead of green. It differs in the class column in that there are no Classes *A*, *I* or *J*,

TABLE E – MILITARY STANDARD MICA-DIELECTRIC CAPACITOR CODE

FIRST DOT ALWAYS BLACK

Color	Second Dot– First Significant Figure	Third Dot– Second Significant Figure	Fourth Dot – Multiplier		Fifth Dot– Tolerance	6th Dot– Class
			Multiplier	Number of Zeros Added		
Black	0	0	x1	Add no 0	±20%	
Brown	1	1	x10	Add 0		B
Red	2	2	x100	Add 00	±2%	C
Orange	3	3	x1,000	Add 000		D
Yellow	4	4				E
Green	5	5				F
Blue	6	6				
Violet	7	7				W
Gray	8	8				X
White	9	9				
Gold			x0.1		±5%	
Silver			x0.01		±10%	

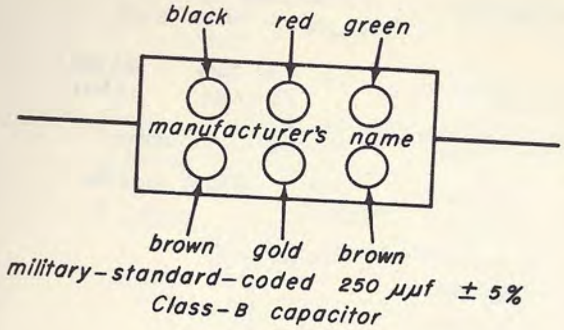


Fig. 3-15

and it has Classes *F*, *W*, and *X*, which the RETMA does not. In this code, a 250-μμf Class *B* capacitor with a tolerance of plus or minus 5% would be coded as follows: black for the first dot, followed by red, green, brown, gold and brown, as shown in Fig. 3-15.

Military Standard Paper-Dielectric Capacitors. Some capacitors that are made for the Armed Forces have paper dielectric and are enclosed in bakelite cases. They look very much like mica-dielectric capacitors, as Fig. 3-16 shows. These capacitors are coded with 6 dots, as shown in Fig. 3-16 just as are the mica-dielectric capacitors. In some cases, however, these capacitors have 3 dots showing on one side and the remaining 3 dots on the other side of the capacitor, as shown in the illustration. In this case, an arrow, or some similar device, as in Fig. 3-16*a*, is used to show which side is read first and the order in which the dots are to be read. The other 3 dots are read just as the second row of dots in the other 6-dot codes, after rotating the capacitor about on the axis of its leads, as in Fig.3-16*b*. In other words, hold the capacitor between thumb and forefinger with the arrows pointing from left to right. The first dot will always be silver to show that it is a paper-dielectric capacitor. The second dot is the first significant figure and the third dot is the second significant figure. Now, still holding the capacitor between your thumb and forefinger, turn it half way around as shown in Fig.3-16*c* and read the remaining 3 dots from right to left. The fourth dot, which is on the right, is the multiplier, the fifth dot is the tolerance, and the dot on the left is the class.

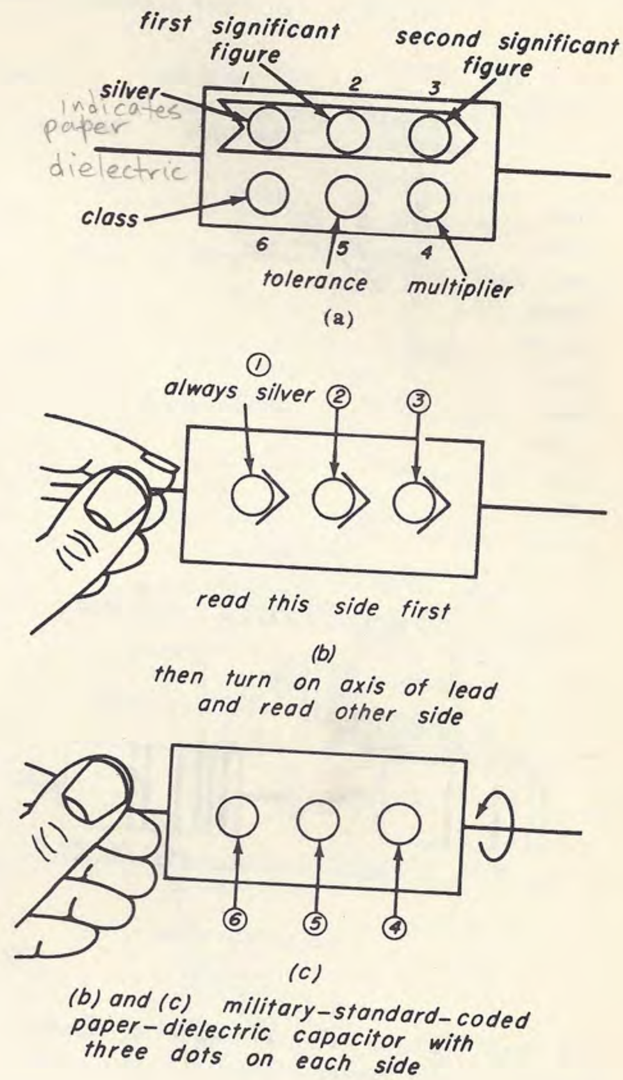


Fig. 3-16

If you examine this code as it is shown in Table F, you will find there are three tolerances shown. Plus or minus 10% is silver, plus or minus 20% is black, and plus or minus 30% is orange. There are no other tolerances. There are two Classes: Class *A* (black) and Class *E* (brown). In replacing such a capacitor, it is important that one of the same class be used.

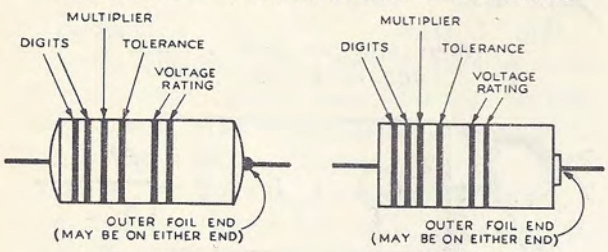
As in the case with the resistor code, not all manufacturers use the capacitor codes exactly as given in this lesson. However, well over 90% of the capacitors that are color coded use these codes as is. If you find one that differs from these codes, you might write directly to the manufacturer for information about his methods of coding.

TABLE F – MILITARY STANDARD PAPER–DIELECTRIC CAPACITOR CODE

FIRST DOT ALWAYS ~~BLACK~~ Silver

Color	Second Dot– First Significant Figure	Third Dot– Second Significant Figure	Fourth Dot – Multiplier: Multiplier	Fourth Dot – Multiplier: Number of Zeros Added	Fifth Dot– Tolerance	6th Dot– Class
Black	0	0	x1	Add no 0	±20%	A
Brown	1	1	x10	Add 0		E
Red	2	2	x100	Add 00		
Orange	3	3	x1,000	Add 000	±30%	
Yellow	4	4	x10,000	Add 0000		
Green	5	5	x100,000	Add 00000		
Blue	6	6				
Violet	7	7				
Gray	8	8				
White	9	9				
Silver					±10%	

COLOR CODE - MOLDED PAPER CAPACITORS



The Voltage Rating is given in hundreds of volts. Only one band is employed for ratings under 1,000 volts. Two bands are employed for ratings over 1,000 volts. Use digit column to read voltage rating.

TOLERANCE	
COLOR	TOLERANCE
BLACK BAND OR NONE	±20%
WHITE OR SILVER	±10%
YELLOW OR GOLD	±5%

Fig. 3-17

Molded Tubular Paper Capacitor Code. Molded tubular paper capacitors are color coded as shown in Fig. 3-17. The colors have the same values as before, except when used in the tolerance position, as shown in the chart in this figure.

3-5. RETMA WIRING COLOR CODE

While no circuit wiring code is in general use among manufactures of home receivers, some manufacturers use the RETMA wiring color code. Manufacturers of commercial communication equipment and all military communication equipment are generally required to use this wiring code. Probably many years will pass before the radio industry adopts it for all radio and electronic equipment. This code is included in this lesson so that you may identify the circuits in receivers that use it. Table G shows the complete wiring code.

TABLE G - RETMA CHASSIS WIRING CODE

Color	Circuit Name
Black	Grounds, grounded elements, and returns
Brown	Heaters or filaments, off ground
Red	Power supply B+
Orange	Screen grid
Yellow	Cathodes
Green	Control grids
Blue	Plates
Violet	Not used
Gray	A-C Power lines
White	Above or below ground returns, AVC, etc.

When leads for antenna and ground connections are provided on the receiver, the antenna lead will be blue and the ground lead black.

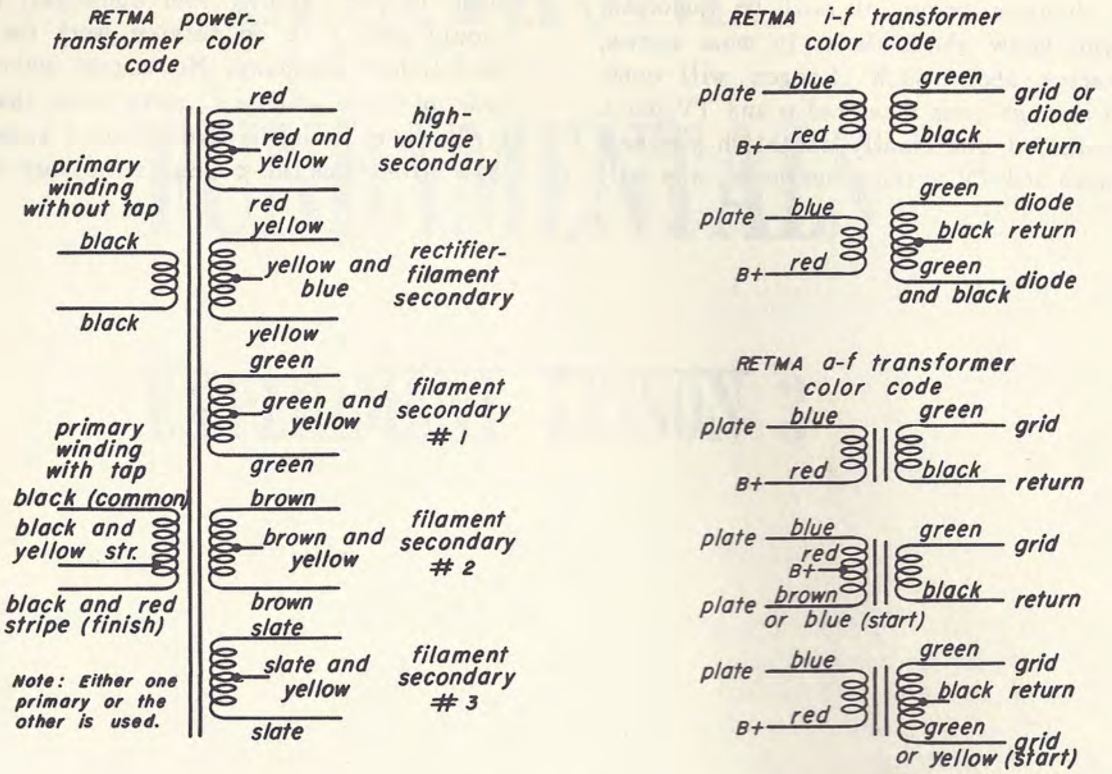


Fig. 3-18

3-6. RETMA TRANSFORMER CODE

Power transformers, intermediate frequency transformers, and audio-frequency transformers frequently come with color-coded leads so that their windings may be easily identified. While you have no immediate need for the transformer code, it is included in Fig. 3-18 for future use. Some of the terms used in identifying some of the windings may be strange to you now. However, by the time you have need for this information, you will know what the terms mean. At that time, it might be a good idea to learn this code.

3-7. RETMA LOUDSPEAKER CODE

Some manufacturers use the RETMA loudspeaker code to identify voice-coil leads and field-coil leads. This code is shown for your future use in Fig. 3-19.

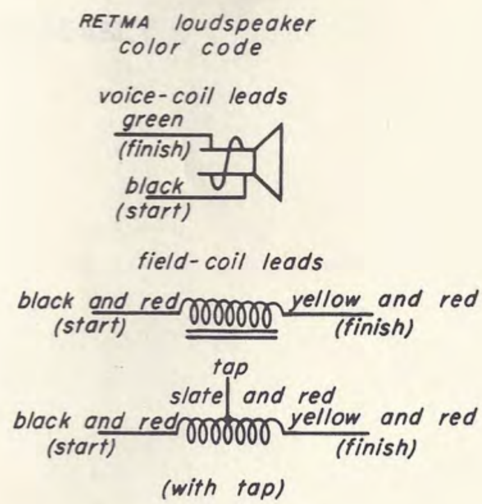


Fig. 3-19

3-8. KEEP UP WITH CODE CHANGES

While not all of the codes included in this lesson are in general use by radio manufacturers, they are well worth knowing about. This is particularly true of the resistor and mica dielectric capacitor codes. There are two or three codes that will be included in later lessons as needed.

An important factor to remember about codes is that they change from time to time.

When changes occur, it will be important that you know about them. In most cases, information about such changes will come to you through your local radio and TV parts distributor, if you finally establish yourself in a radio and TV service business, or it will come to you through your employer, if you should decide to do service work for some established company. No matter where you hear of code changes, make sure that you study them carefully; you should know how they differ from the codes as they are now.

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 3

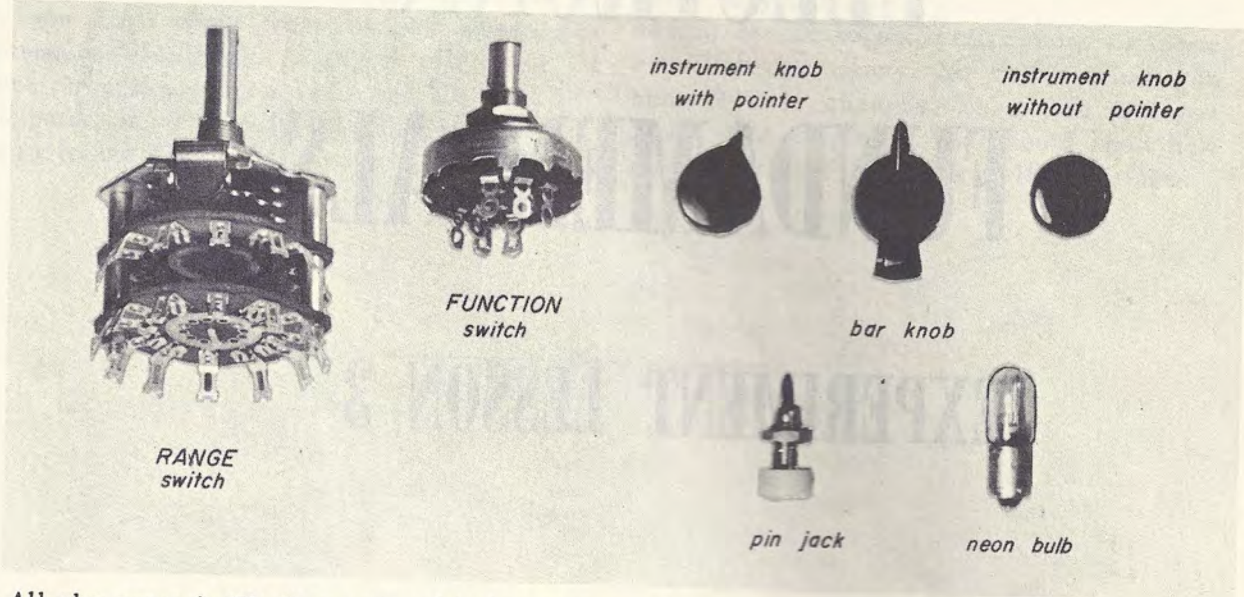
STARTING THE MULTIMETER ASSEMBLY

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 2 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 2

Quantity	Item
1	Meter box
1	Meter panel
1	Switch (RANGE), 2-pole 11-position, with lockwasher, index stop, flat washer, nut
1	Switch (FUNCTION), 2-pole 3-position, with lockwasher, flat washer, nut
1	Resistor, 8 megohms, 1/2 watt, 1%
1	Resistor, 1.5 megohms, 1/2 watt, 1%
1	Resistor, 400 k-ohms, 1/2 watt, 1%
1	Resistor, 80.1 k-ohms, 1/2 watt, 1%
1	Pin jack, yellow plastic cap, with nut
1	Pin jack, red plastic cap, with nut
1	Pin jack, black plastic cap, with nut
1	Neon lamp
5	Red #20 solid pushback wire
5	Black #20 solid pushback wire
1	Instrument knob with pointer and set screw
1	Instrument knob, without pointer, with set screw
1	Bar knob with set screw
4	Screw, binding head, 3/8"

If you get a part slightly different from a part described in this list, the substitute part will not interfere electrically or mechanically with your experiments or equipment.

Experiment Lesson 3

OBJECT

In this lesson, you will apply the knowledge of the skill in soldering you gained in the first two Experiment Lessons by starting to wire a multimeter.

CHECK KIT

Unpack the parts in Kit 2 carefully, and check them against the illustrations and the list on Page 2.

After checking the parts, place the little neon bulb away safely where you can find it for use in the next Experiment Lesson. To prevent the resistors from being damaged, place them back in the envelope in which they came. Then place these and the other small parts in some container, where you will find them when you need them.

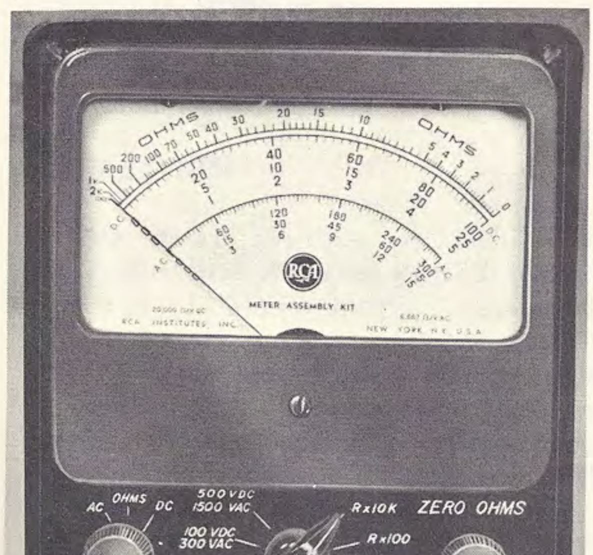


Fig. 3-1

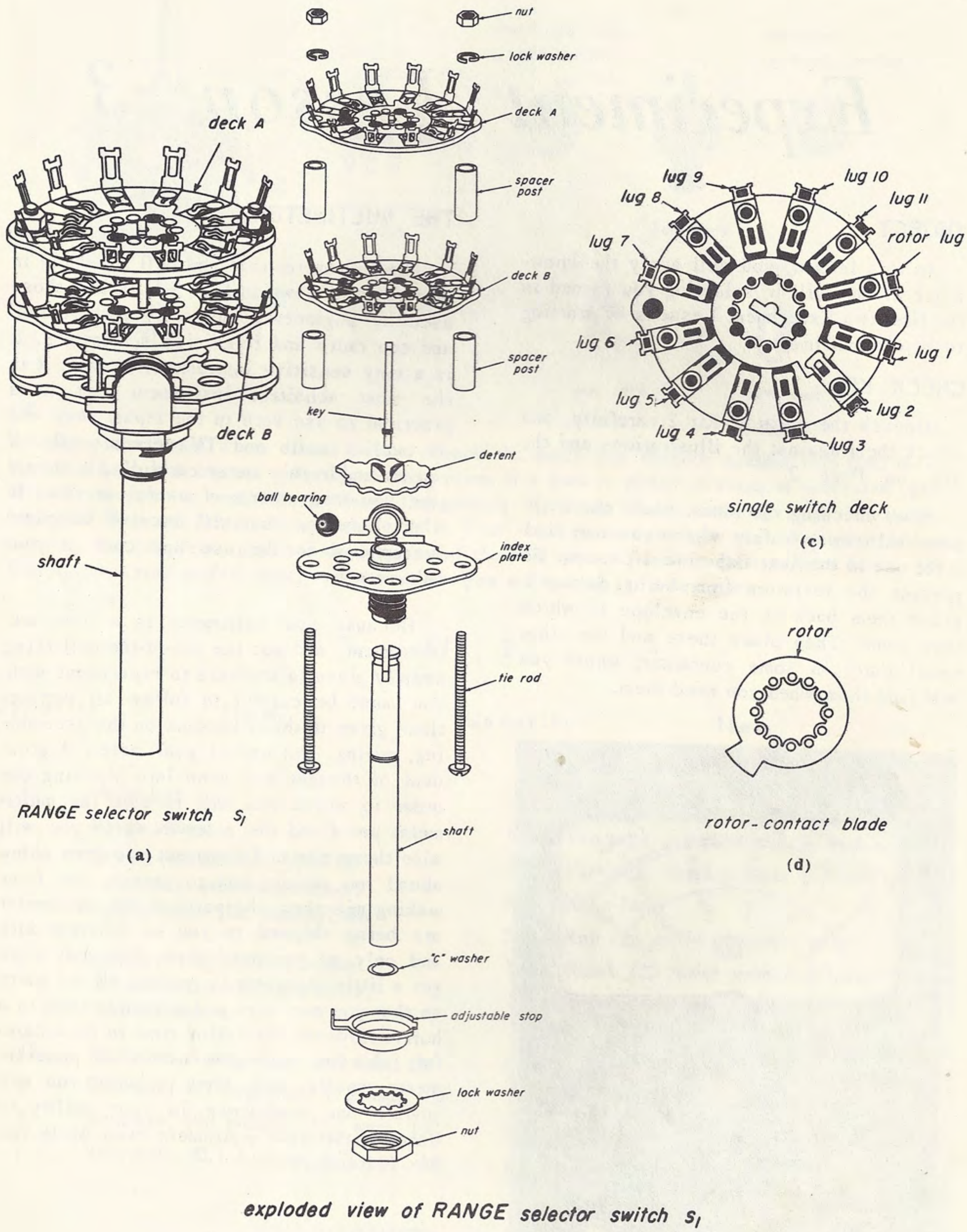
THE MULTIMETER

The multimeter that you will assemble in this course (shown in Fig. 3-1) is like those used by engineers, laboratory technicians and top radio and television servicemen. It is a very sensitive instrument. In fact, it is the most sensitive instrument that it is practical to use both in the repair shop and on outside radio and TV service calls. If you assemble this meter carefully, it should give you many years of useful service. In other lessons, you will receive complete instructions in the use and care of your multimeter.

Because your multimeter is a first-rate instrument, and not the run-of-the-mill thing usually given to students to experiment with, you must be careful to follow all instructions given in these lessons on the assembling, wiring, and use of your meter. A great deal of thought has gone into planning the order in which you will receive the multimeter parts and the order in which you will wire these parts. To prevent you from going ahead too rapidly and to prevent you from making mistakes, the parts of the multimeter are being shipped to you in different kits and only as you need them. You may even get a little impatient to receive all the parts so that you may wire and assemble them in a hurry. However, by taking time to do a careful job, you will save money on possible meter repairs, and, what is more, you will justify our confidence in your ability to handle first-class equipment even while you are learning.

METHOD

To reduce the chance of making mistakes, to make the wiring job easier, and to make



RANGE selector switch S_1

(a)

exploded view of RANGE selector switch S_1

(b)

single switch deck

(c)

rotor-contact blade

(d)

Fig. 3-2

sure that each part is placed where it belongs, the assembling and wiring of parts is laid out in several series of steps. A drawing showing the actual work to be done is given with each series of steps so that the wiring may be checked and double-checked as you go along. By doing each step of assembling and wiring in the order given, you will do a more professional looking job — one to be proud of.

EQUIPMENT NEEDED

Kit 2

Soldering iron

Cloth

Solder

Long-nose pliers

Diagonal cutting pliers

Adjustable crescent wrench or one 5/8", one 1/2", and one 9/16" open-end, or box wrench

Fine-blade screw driver

Ruler

INFORMATION

Two rotary switches are included in Kit 2. The first of these, RANGE selector switch S_1, is shown in Fig. 3-2*a* and *b*. The first drawing shows the switch as it actually is; the second shows what is called an *exploded view* of the same switch, showing the parts that make up the switch. If you examine it, you can see that the switch is made up of two layers of contacts, placed one above the other. Each of these layers is called a *deck* or *wafer*. Looking at Fig. 3-2*c*, you can see that each wafer has twelve contact lugs, mounted in a circle around a movable metal ring. This metal ring, shown separately in Fig. 3-2*d*, is called a *rotor*, because it rotates or turns around as the shaft turns. You will notice that the rotor has a tab, or contact blade, that makes contact, one at a time, with each of the contact lugs, numbered from one to eleven. The remaining contact lug extends farther out toward the center and makes contact with the rotor ring in all switch positions. For this reason, it is called a *rotor contact lug*. This deck, therefore, is known as a single-pole, eleven-position deck, and the entire switch is known as a two-pole, eleven-position switch. The decks are identified in Fig. 3-2*a* by the letters *A* and *B*.

The FUNCTION switch, S_2, shown as it actually looks in Fig. 3-3*a* and in an exploded view in Fig. 3-3*b*, is a two-pole, three-position switch. Select this switch from the parts in Kit 2 and examine it closely. You will find that all you can see is a shaft, a switch cover, and a wafer with eight lugs. What happens inside the switch is hidden from your view. By examining the exploded view of Fig. 3-3*b*, you can see how this switch is put together. Fig. 3-3*c* shows the hidden side of the switch wafer. You can see two groups of contacts, one marked *A* and the other *B*. Each of these groups is made up of three numbered contacts; each contact is part of the lug marked with the same number. Connected to each rotor lug is the metal rotor plate with finger-like projections spread out between the numbered contacts. Switching is done by rotating the shaft, which is connected to an insulating wafer upon which are mounted rotor shoes — one for each group of contacts. As shown in Fig. 3-3*d*, as the shaft rotates, each rotor shoe makes connection, between its rotor plate and one of the numbered contacts. So each group of contacts, together with its rotary contact, makes up a single-pole, three-position switch, and the two groups and their rotary contacts unite to form a two-pole, three-position switch. *Do not attempt to take this switch apart to examine it.* If you do, you may break the insulating wafer or find it very difficult to reassemble the switch properly.

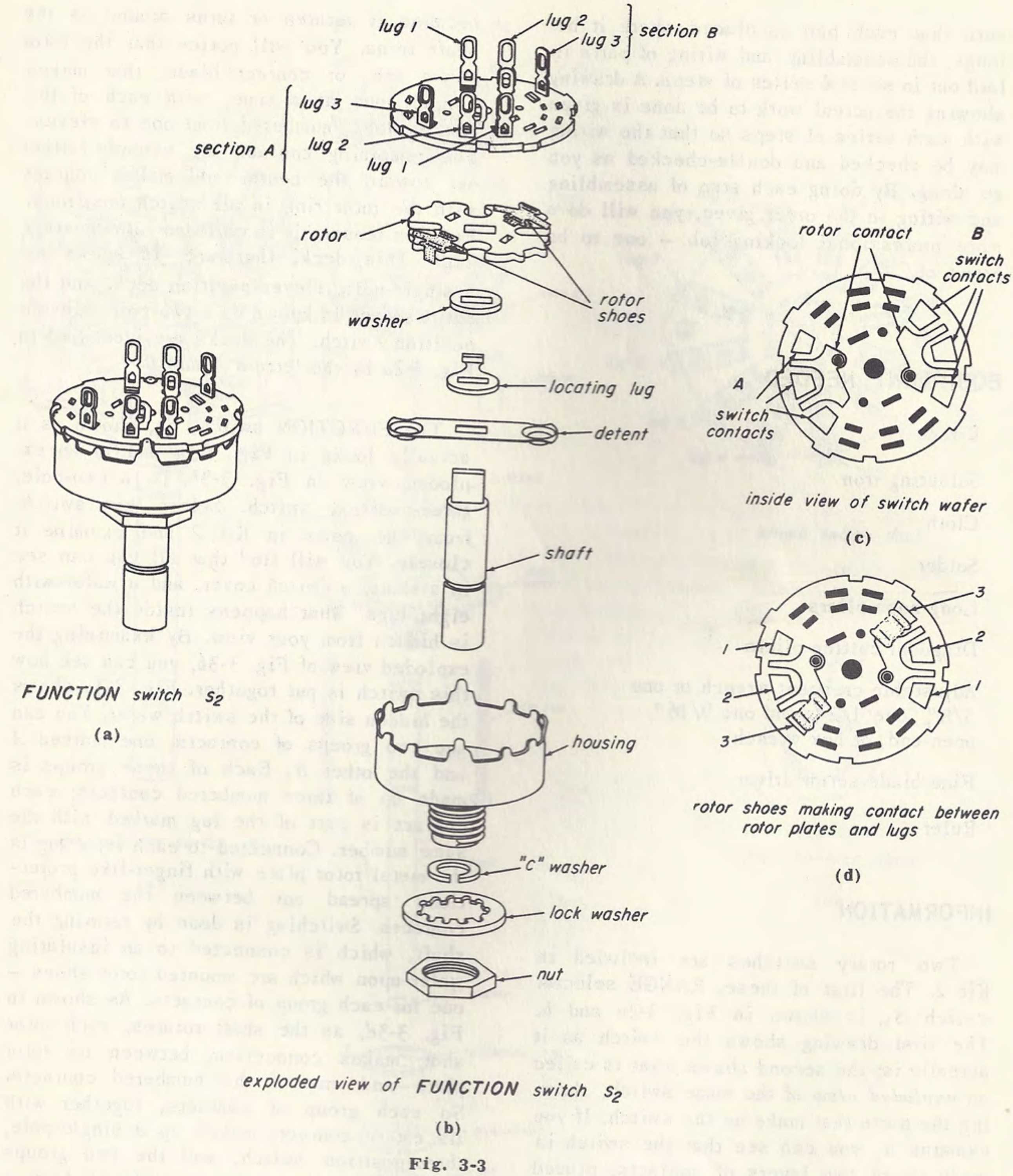


Fig. 3-3

PREPARATION

1. Before mounting or wiring any parts, check the photograph that is shown in Fig. 3-4. It shows how the parts received in Kit 2 are assembled. See how they look when they are mounted and wired according to the instructions that follow. In other words, get some idea of what you are going to do before you do it.

2. Prepare your bench or table for work,

with tools and the parts from Kit 2 laid out for work.

3. Be sure that your soldering iron is clean and tinned, ready to be heated and used.

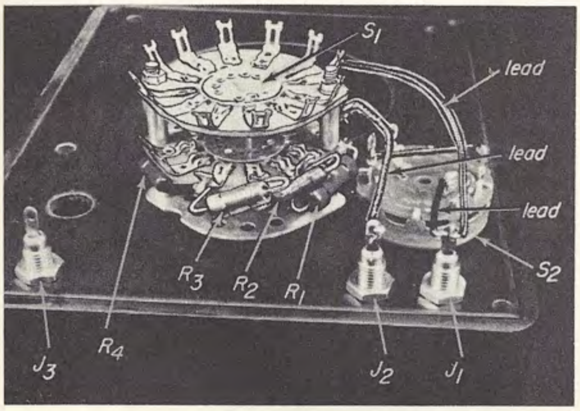


Fig. 3-4

JOB 3-1

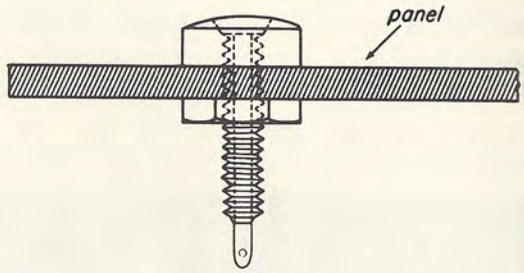
To mount the three colored pin jacks as shown in Fig. 3-5 *a* and *b*.

Procedure.

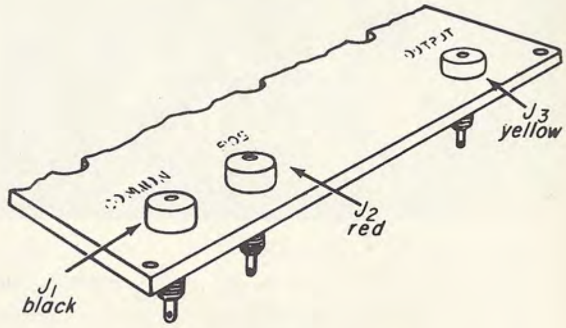
Step 1. Mount black pin jack J_1. To do this, place the threaded shaft of the jack through the hole, as shown in the picture diagram, and tighten in position with one of the jack mounting nuts, using a 3/8 inch wrench or a crescent wrench. If you haven't either of these tools, you may use adjustable combination pliers (gas pliers). In fact, you may use them wherever a wrench is called for in these instructions. However, if possible, avoid the use of these adjustable pliers, as they tend to bite into the nuts and leave them misshapen. When properly mounted, the black insulation of the pin jack should face you as you look at the front of the cover panel.

Step 2. Mount red pin jack J_2 in the same way. Be sure that it is in the position shown in Fig. 3-5.

Step 3. Mount yellow pin jack J_3 in the same way in the remaining pin jack hole, as shown in Fig. 3-5.



(a)



(b)

Fig. 3-5

JOB 3-2

To mount RANGE selector switch S_1 exactly as shown in Fig. 3-6*a*.

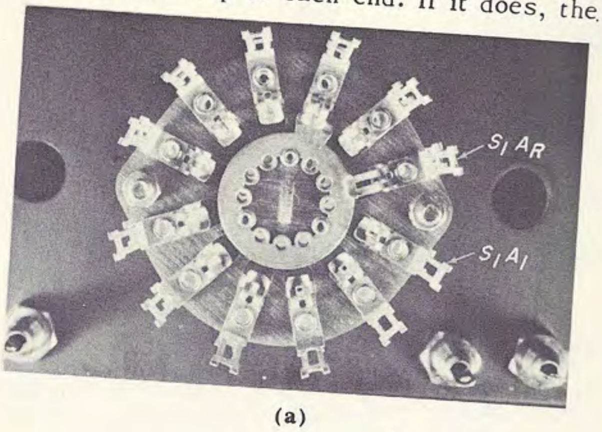
Procedure.

Step 1. Be sure that the rotor lugs are in the position shown (see position of S_1A_R in Fig. 3-6*a*) and that the *adjustable stop* is in the proper hole, as shown in Fig. 3-6*b*, before pushing the shaft in the hole in the panel.

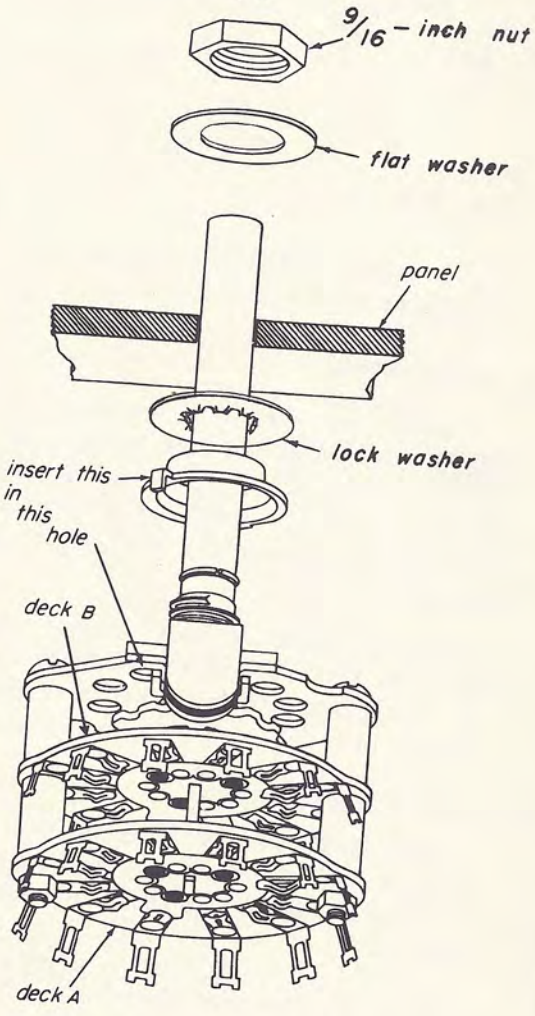
Step 2. Place a lock washer over the threaded shaft. Insert the shaft in the hole. On top, place a flat washer over the shaft. Fasten in place with a 9/16-inch nut.

Step 3. Place the knob on the RANGE selector switch shaft and tighten the set screw to the shaft with the fine-blade screwdriver.

Step 4. Test the switch to see if the adjustable stop is in the correct position. To do this, turn the switch knob in a clockwise direction until it stops. Then, as you turn the knob in a counterclockwise direction, count the number of clicks the rotor makes until it stops at the other end. If the adjustable stop is in the correct position, you should hear nine clicks. Note, too, whether the switch slips around on the panel as you come to the stop at each end. If it does, the nut on the switch shaft needs further tightening.



(a)



Detail of mounting switch S_1 on meter panel

(b)

Fig. 3-6

Step 5. Turn the switch to its extreme counterclockwise position. Unscrew the knob. Line up the knob pointer with the RX10K line. Tighten the screw on the knob.

JOB 3-3

To mount FUNCTION switch S_2 with its lugs in the position shown in Fig. 3-7.

Procedure

Step 1. Slip a lock washer over the threaded part of the shaft. Push the FUNCTION switch shaft through the proper hole in the panel. Place a flat washer over the shaft and fasten in place with a 1/2-inch nut.

Step 2. Place the small pointer knob on the switch shaft. Tighten the set screw. Turn the knob all the way clockwise. Line up the knob pointer with the DC line and tighten the set screw to the shaft with your fine-blade screwdriver.

Step 3. Turn the knob counterclockwise until it stops. Then turn it in the opposite direction. You should hear the second click as it comes to a stop.

Step 4. Place the meter box on a bench or a table and place the cover panel upside down on the four corner mounting posts in the box, as shown in Fig. 3-8. In this way, the meter box acts as a convenient support for your work. It prevents scratching or otherwise damaging the face of the cover panel. (In radio and electronics factories, supporting

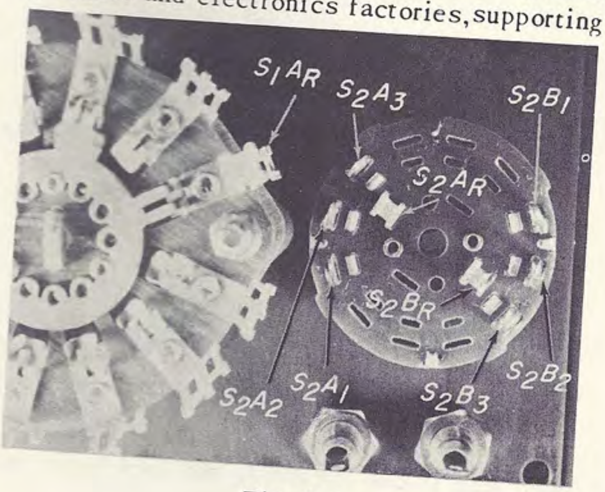


Fig. 3-7

clamps or box forms, called *jigs*, are used to hold a radio or other chassis in position for easy work.) Your meter box, therefore, becomes a jig to keep your meter panel and mounted parts steady while you work on them.

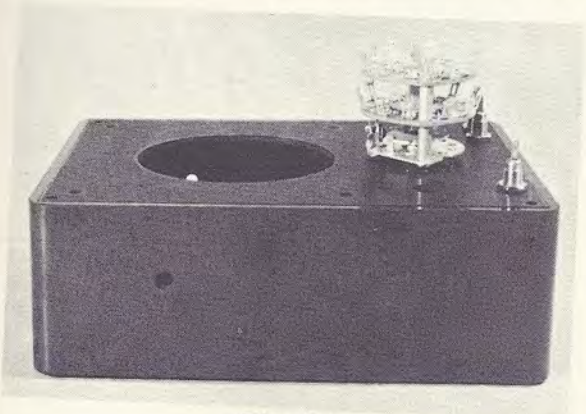


Fig. 3-8

JOB 3-4

To mount the first resistor, R_1, on Switch S_1.

Information. In the following steps, the actual wiring begins. At this point, it would be a good idea for you to check your soldering iron and connect it to your electric outlet so that it will be ready for use when you need it. While your soldering iron is heating, turn back to Fig. 3-4, and see the wiring that you are actually going to do in this lesson.

Doing a neat, accurate job of wiring, such as is shown in the picture, calls for good soldering. Use no more solder than is necessary to make a good joint. You can readily see that using too much solder on the switch lugs, for example, may cause them to touch each other. This might easily cause damage to your meter the first time you use it. Whenever, in the following steps, you connect a resistor or a wire to one of the switch lugs, make very, very sure that the resistor or wire is connected to the proper lug. To help you do this, each switch lug is numbered in all drawings, and each switch jack or section is lettered. With a little care, you can avoid making errors. Remember that you cannot afford to make a wrong connection without risking the danger of damaging the meter movement.

In the instructions that follow, you will find some that tell you to connect some part or lead to a particular terminal. This means that a good tight connection should be made *without soldering*. The reason for this is that, in wiring this meter, sometimes two, three, or even more leads are connected to the same terminal or lug. Therefore soldering is not done until the last connection is made.* For example, if you look at Fig. 3-4, you will find that two leads are connected to pin jack J_1. So, when the connection is made between the rotor lug *B* of switch S_2 to the pin jack, it is done without soldering. Later, when rotor lug *A* of switch S_1 is connected to the same pin jack, both connections are soldered at the same time. In some cases, the instructions tell you to solder a lead or resistor to a certain lug. This means that you must first make a good tight connection and then solder it.

You may find that some of the resistor leads are dull from oxidation or dirty from handling, even though they are tinned. If so, before connecting and soldering them, clean them lightly with fine sandpaper.

The wiring you will do in this lesson is shown in schematic form in Fig. 3-9. After you are familiar with such circuits, it will be possible, sometimes, to make connections and to do wiring without further information. However, to be on the safe side, it is better to follow the step-by-step directions that follow.

Procedure.

Step 1. Prepare the 8-megohm resistor, R_1, by removing one-half inch of wire from each end with your diagonal cutting pliers, as shown in Fig. 3-10*a*.

*You may remember that, in the two soldering lessons, you were told to solder each connection as you went along — to make sure none were forgotten. This advice is still good for most wiring. However, in these instructions, you will be reminded to solder any connection that you are told to connect, so there is no danger of you forgetting.

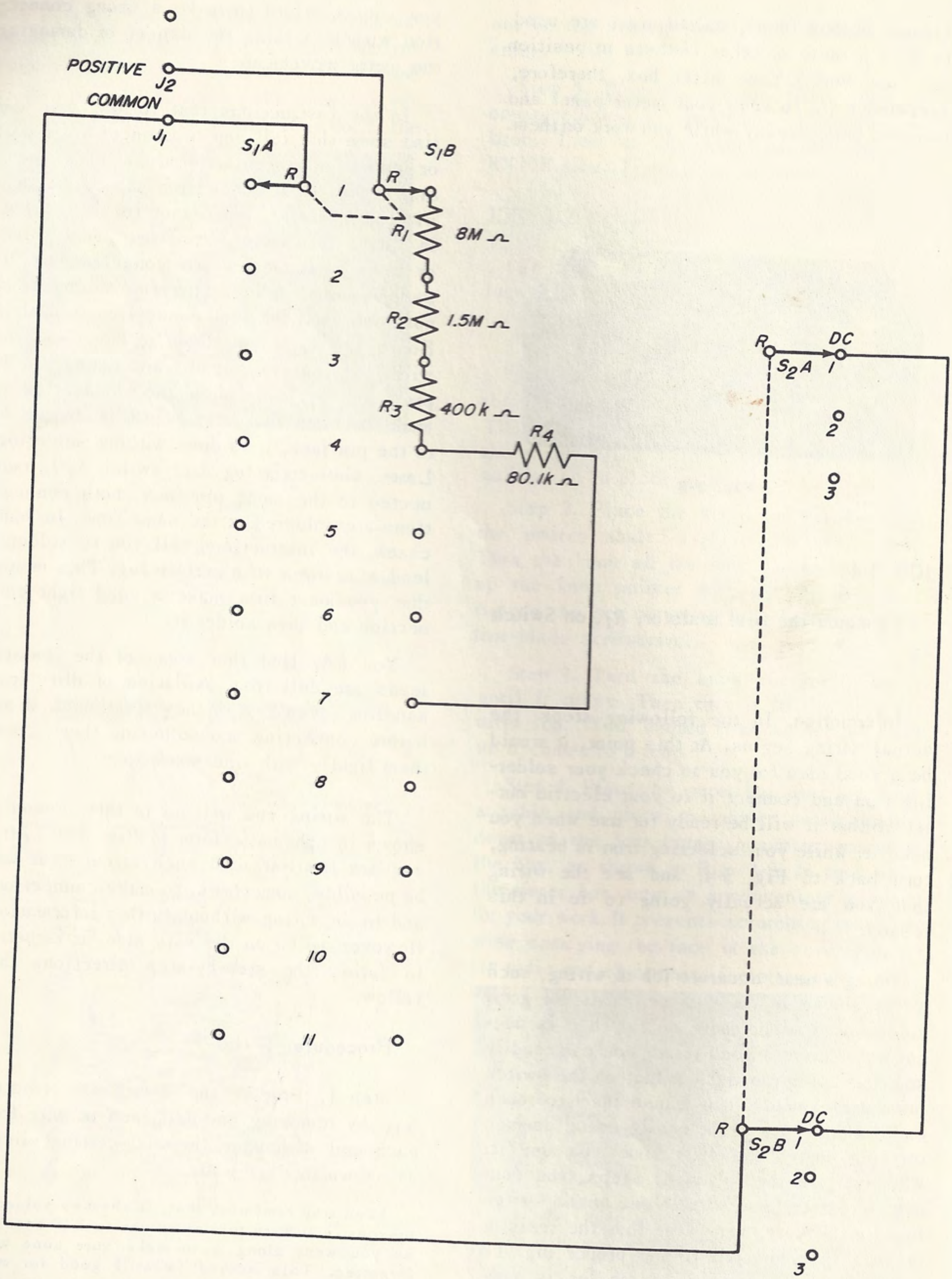
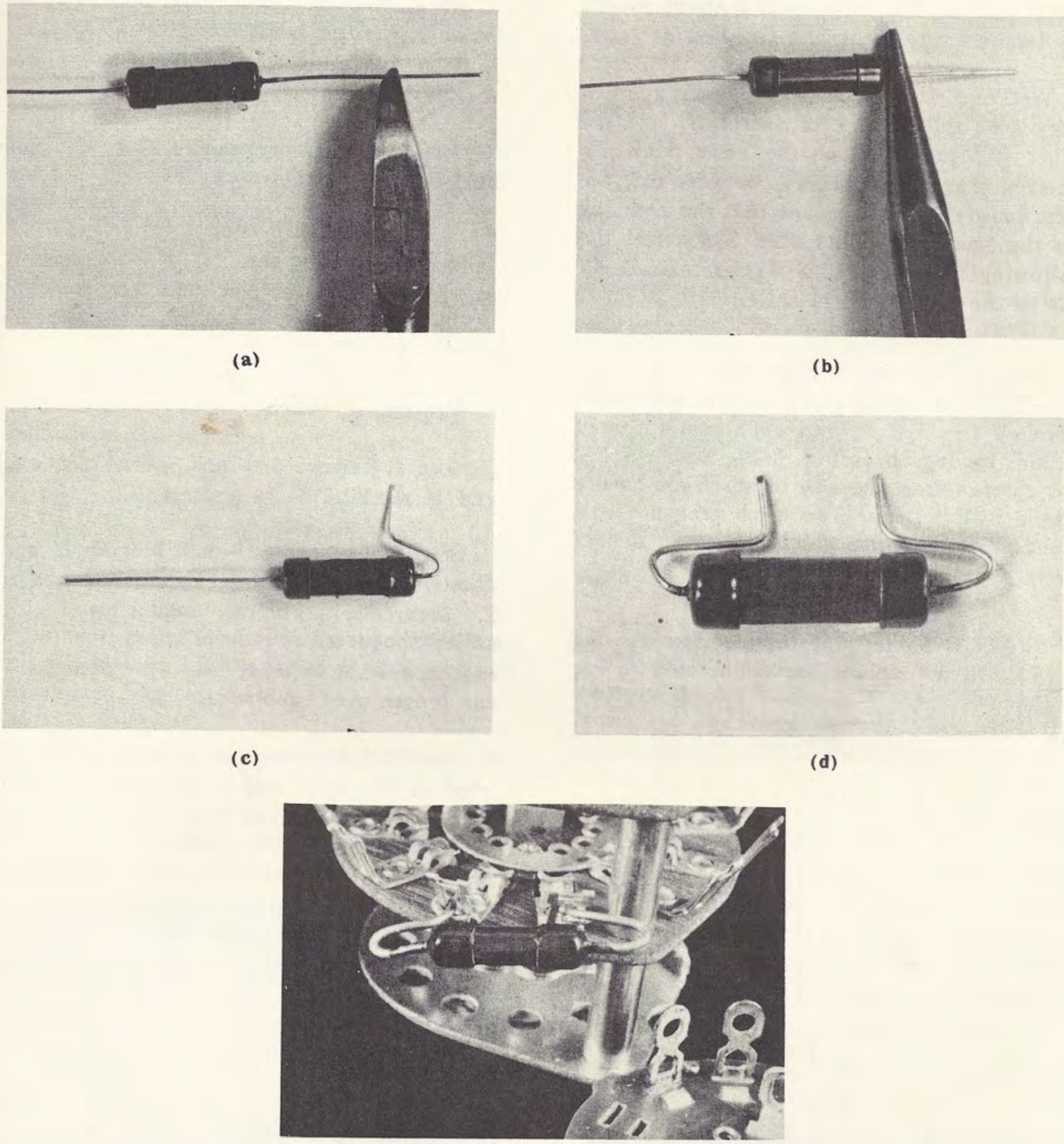

POSITIVE
J2
COMMON
J1
S1A
S1B
R
R
1
R1
8M Ω
2
R2
1.5M Ω
3
R3
400k Ω
4
R4
80.1k Ω
5
6
7
8
9
10
11
R
DC
S2A
1
2
3
R
DC
S2B
1
2
3

Fig. 3-9



(a) (b) (c) (d) (e)

Fig. 3-10

Step 2. If necessary, clean the resistor leads lightly with fine sandpaper. Do not remove the tinning.

Step 3. Place one of the resistor leads between the jaws of your longnose pliers, as shown in Fig. 3-10*b*. Then bend the lead into the shape shown in Fig. 3-10*c*. Be sure to bend the lead and not the body of the resistor. By holding the lead with the pliers, you are prevented from making too short a bend, and, consequently, from breaking the lead off from the resistor. Next, place the pliers at the other end and bend the lead in the same way. When this work has been done, the resistor will look as it does in Fig. 3-10*d*. The distance between the leads should then be the same as the distance between lug *1* and lug *2* on deck *B* of RANGE switch S_1 (approximately one-half inch).

NOTE: One end of this resistor goes to lug *1* on the *B* deck of switch S_1 and the other end to lug *2* on the same deck. To shorten these instructions, we will call the first lug S_1B_1. This means that the next lug on the same deck is called S_1B_2, and the following lug is called S_1B_3, *etc. The rotor* lug on the same deck is called S_1B_R.

Step 4. Slip one lead resistor R_1 through the long hole in lug S_1B_1 and the other lead through lug S_1B_2. Wrap each resistor lead around its lug, as in Fig. 3-10*e*. Solder S_1B_1. Be careful about the way in which you handle these switch lugs. Too much pressure will bend or break them, which may make it necessary to replace the switch.

Step 5. Solder the connection to lug S_1B_1. Do not solder the connection to lug S_1B_2 yet.

JOB 3-5

To mount the second resistor, R_2, on switch S_1. In the last procedure, each step was given in exact detail because it was the first time you were going through these operations. It is not necessary to repeat all these instructions for the next few steps because the work is done the same way in each case.

Procedure.

Step 1. Prepare the 1.5-megohm resistor, R_2, as you did R_1.

Step 2. Solder one end to S_1B_2. Connect the other end to S_1B_3.

JOB 3-6

To mount the third resistor, R_3, on switch S_1.

Procedure.

Step 1. Prepare the 400 k-ohm resistor, R_3, as before.

Step 2. Solder one end to S_1B_3 and connect the other end to S_1B_4.

JOB 3-7

To mount the fourth resistor, R_4, on Switch S_1.

Procedure.

Step 1. Remove 5/8-inch of lead from each end of the 80.1 k-ohm resistor, R_4.

Step 2. Cut two 5/8-inch lengths of spaghetti. (As you know from Experiment Lesson 2, servicemen use an insulating tubing, called spaghetti, to prevent wires from touching each other or other metal surfaces.) Slip one length over each lead of R_4.

Step 3. Solder one end of R_4 to S_1B_4 and connect the other end to S_1B_7, as shown in Fig. 3-11. Be sure to keep the body of the resistor below the 5th and 6th lugs on the same deck, because in another lesson you will connect other resistors to these lugs. Also be sure that no part of the bare resistor lead touches the spacer post between the 6th and 7th lugs.

JOB 3-8

To make the connections between the red

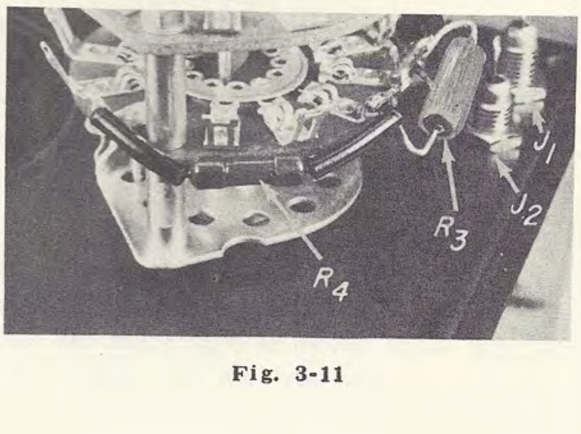


Fig. 3-11

and black pin jacks and the RANGE selector switch and the FUNCTION switch.

Procedure.

Step 1. Cut a 1-1/2-inch length of solid hook-up wire. Remove 1/4-inch of insulation from each end.

Step 2. Solder one end to S_2B_R and connect the other end to the black pin jack J_1, as shown in Fig. 3-12.

Step 3. Cut one 2-1/2-inch length of solid hook-up wire. Remove 1/4 inch of insulation from each end.

Step 4. Solder one end to the red pin jack J_2 and solder the other end to S_1B_R (the rotor lug on the B deck on Switch S_1).

Step 5. Cut one 2-3/4-inch length of solid hook-up wire. Remove 1/4-inch of insulation from each end.

Step 6. Solder one end to the black pin jack, J_1, and solder the other end to S_1A_R.

Note: Make sure that neither wire nor solder from either of these rotor connections on S_1 touches the metal post and the screw next to the rotor lugs.

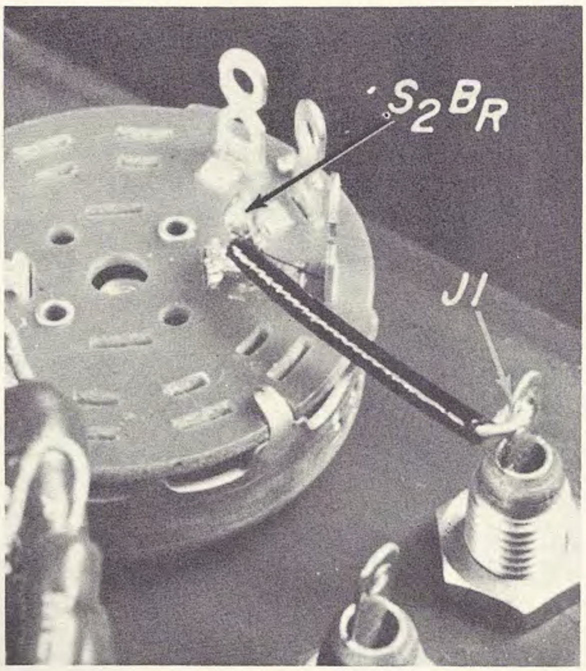


Fig. 3-12

JOB 3-9

To connect S_2A_1 to S_2B_1.

Procedure.

Step 1. Cut one 1-3/4-inch length of hook-up wire. Remove 1/4 inch of insulation from each end.

Step 2. Solder one end to S_2A_1 and solder the other end to S_2B_1, as shown in Fig. 3-13.

CHECK YOUR WORK

With this last connection, you have finished the first part of your multimeter wiring. Before you put it aside to wait for the parts included in Kit 3, examine your work carefully. Make the following checks:

1. See if the resistors you have connected to the RANGE switch S_1 are of the values called for by the instructions.

2. Make sure that the resistors and wires are connected to the lugs called for in the wiring instructions.

3. Make sure that no bare wire touches any other bare wire or metal surface, except

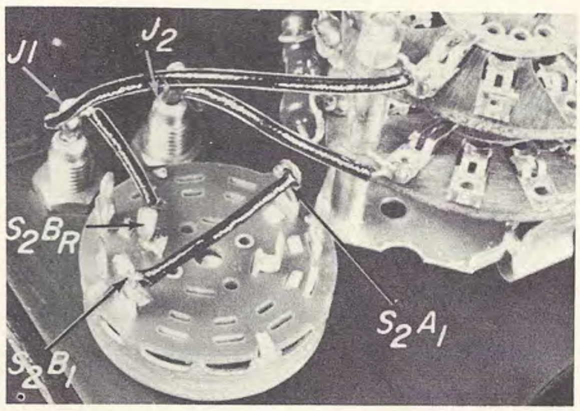


Fig. 3-13

where the instructions call for wires to be connected to the same lug.

4. Be sure that the soldering is well done, without cold solder joints or excess solder.

5. When you are satisfied that your work is done correctly and well, place the meter panel on the meter box so that the switches and resistors are inside and the front of the panel faces up. Carefully place your partly constructed meter away, where it will be safe until you need it next. It is a good idea to cover the meter so that dust and dirt do not get between the switch contacts.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 4

ELECTRON THEORY AND CURRENT

RCA ®

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HOME STUDY SCHOOL

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

Theory Lesson 4

INTRODUCTION

We cannot see, hear, feel, taste, or smell electricity, yet we know that it exists because of some of the effects it produces. When we turn on an electric lamp, electricity must be present because we see light. If we connect an electric iron to an electric outlet, electricity must be flowing because the iron gets hot. Electricity flowing through liquids has a chemical effect; this effect is used in electroplating metals. When you touch the terminals of an electric power source, no one has to tell you that electricity is present – the shock is proof positive!

Although we use electricity to do many things and can measure it with accuracy, we have no exact knowledge of its nature. Many theories have been developed to explain what happens in electric circuits. One theory, while it does not explain everything, is generally accepted. It is called the *electron theory*.

4-1. STRUCTURE OF MATTER

Before studying the electron theory, we must know something of the structure of matter. All substances are composed of *elements*. An element is a substance that cannot be broken into simpler parts by ordinary chemical means. There are 92 natural elements. In addition, there are several man-made elements, which are produced in atomic-energy research. All things, animal, vegetable, and mineral – even the air we breathe – are made up of these elements.

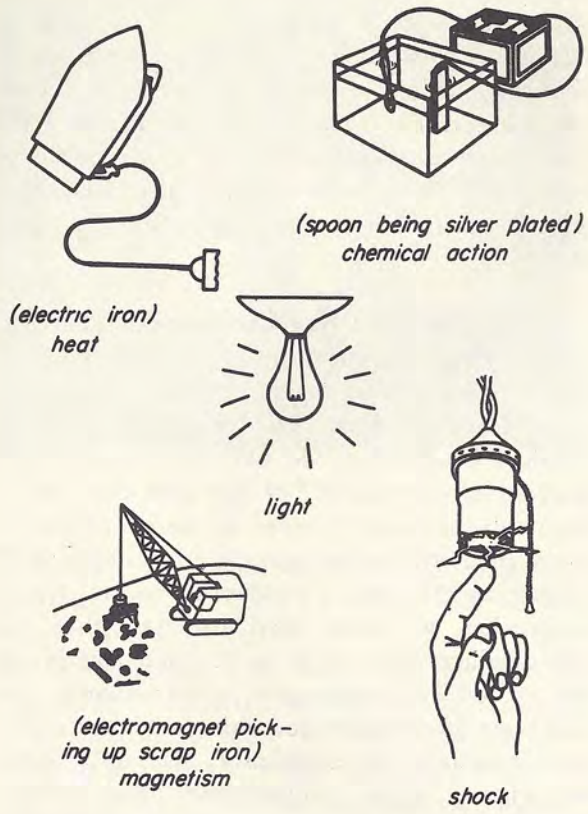
For that reason, they are sometimes called the "building blocks of the universe". Some substances, such as copper, lead, iron, and oxygen are pure elements. Other substances, such as water, table salt, and wood, are made up of two or more elements. We call these substances *compounds*. The smallest divisible particle of a compound is called a *molecule*. Molecules may be broken up into the smallest bits of matter of which their elements are composed – atoms. The molecule and the atom are so very small that they cannot be seen, even under the strongest microscope.

4-2. ELECTRON THEORY OF MATTER

Most modern scientists believe tha atoms are made up of positively and negatively charged particles. Negative particles are called *electrons*, and positive particles are called *protons*. We may think of all the atoms of any one element, in the normal neutral state, as being exactly alike in the number of electrons and protons they contain. Atoms of *different* elements differ only in the number of electrons and protons they contain. For instance, an atom of hydrogen contains one electron and one proton, while an atom of oxygen contains eight electrons and eight protons.

Atoms have been compared to sola systems, like the system including our su and its planets. The central part of eac atom, called the *nucleus*, contains all th protons. Whirling around the nucleus, ver much like the planets around the sun, ar the electrons. The negative charge of eac electron is exactly equal to the positiv charge of each proton. Thus, the total posi tive charge of an atom will, under ordinar conditions, equal the total negative charge

Figure 4-2*a* is a drawing of the hydroge atom. In the center is the nucleus with it one proton. Traveling in its orbit around th nucleus is one electron. While the proton an



Five ways in which electricity is known to us.

Fig. 4-1

the electron are the same size, the proton is more than 1800 times as heavy as the electron. Figure 4-2*b* shows an atom of helium, with two electrons in their orbits around the nucleus. In the nucleus are two protons and two *neutrons.* The neutron is about the same size and weight as a proton, but is neutral in charge. Scientists believe that a neutron is formed by an electron and a proton combining in the nucleus. Because the individual charges of the proton and electron are equal and opposite, they neutralize each other.

The atomic weight of an atom is determined by the weight of the protons and neutrons in the nucleus. (Neutrons are not important in the study of radio and television, but are very important in the study of atomic energy.) Notice that the orbits of the electrons in the helium atom are of the same size. Now consider the drawing of the beryllium atom, in Fig. 4-2*c*. Note that the nucleus contains four protons and five

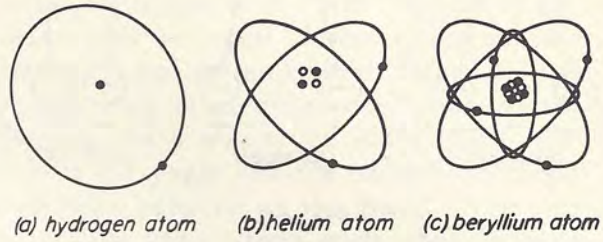


Fig. 4-2

neutrons. Also, note that two of the electrons have orbits of one diameter and two electrons have orbits of a larger diameter. Two electrons in the larger orbits are farther from the nucleus than are the other, inner electrons. Electrons travel at fixed distances from the nucleus. All electrons traveling at the same distance from the nucleus have orbits of the same diameter, and are said to be in the same *shell* or *ring*. In the innermost shell, there is room for only two electrons. If an atom contains more than two electrons, a second shell is formed. This shell may have as many as eight electrons. Thus, in the first two shells, an atom may have as many as ten electrons; two in the first shell and eight in the second. If there are more than ten electrons, a third shell is formed, and so on. The third shell may contain as many as eighteen electrons, the fourth shell as many as thirty-two, and the fifth shell as many as fifty.

4-3. LAW OF CHARGES

All electrons are exactly alike and all protons are alike, no matter whether they are from an atom of hydrogen or an atom of gold. They all obey one of the basic laws of electricity: *Like charges repel each other, and unlike charges attract each other.* This means that electrons repel each other, protons repel each other, and electrons and protons attract each other. This is shown in Fig. 4-3.

When an atom loses one or more electrons, the protons of the nucleus seek to attract other electrons to balance their positive charge. Under normal conditions, atoms tend to have equal positive and negative charges and to be electrically neutral.

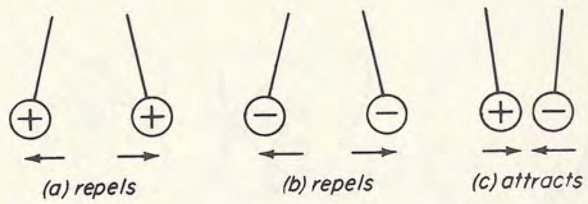


Fig. 4-3

4-4. ELECTRIC CURRENT

Under certain conditions, an atom can be forced to take more than a normal amount of electrons. When this happens, the atom tends to pass its excess electrons to some nearby atom. The electrons that it passes on are not necessarily those it gets. Figure 4-4 shows a possible path of electrons passing from atom to atom in a piece of carbon. Assume that electron *A* has just attached itself to atom 1. Normally, a carbon atom has four electrons in its outer shell; this one now has five. It therefore passes electron *B* to atom 2. Atom 2 in turn, passes electron *C* to atom 3, and so on. This transfer of electrons is practically instantaneous and continues until some atom gets rid of the excess as a *free* electron or until an atom which has a deficiency of electrons receives it. This movement of electrons from atom to atom is what we call *electric current.* We will study more about it later.

Free Electrons. Most electrons remain permanently in their atoms. In some materials however, one or more of the electrons in the outermost shell are loosely attached. With very little pressure applied to them, they may be detached from their atoms and become *free electrons.* In fact, in some materials electrons exist as free electrons even before any pressure is applied. Such metals as silver and copper have many free electrons. Glass, rubber, mica, and some other substances, on the other hand, have very few free electrons. Naturally, electricity will flow more easily when it is easy to move electrons. This helps to explain why certain metals conduct electricity more readily than others.

Conductors and Non-Conductors. Electric current depends upon the movement of electrons. Copper and silver, because of their many free electrons, are frequently used to conduct electricity. We call them good conductors of electricity, or say that they have high *conductivity.* Copper is more commonly used than silver because it is cheaper and almost as efficient a conductor. In radio and television, we often need materials that do *not* conduct electricity well. Such materials are called *non-conductors,* or *insulators.* An insulator is a substance that is a relatively poor conductor of electricity. Materials such as glass, mica, polystyrene, and rubber have so few free electrons that they make poor conductors but excellent insulators. Figure 4-5 shows some insulators.

No known substance is a perfect insulator – one that passes no electrons, regardless of applied pressure. Every insulating material is good only to a certain point, depending upon the material. When the applied pressure is high enough, any insulator breaks down.

4-5. STATIC ELECTRICITY

Thus far, we have mentioned only electricity in motion, or current. However, there

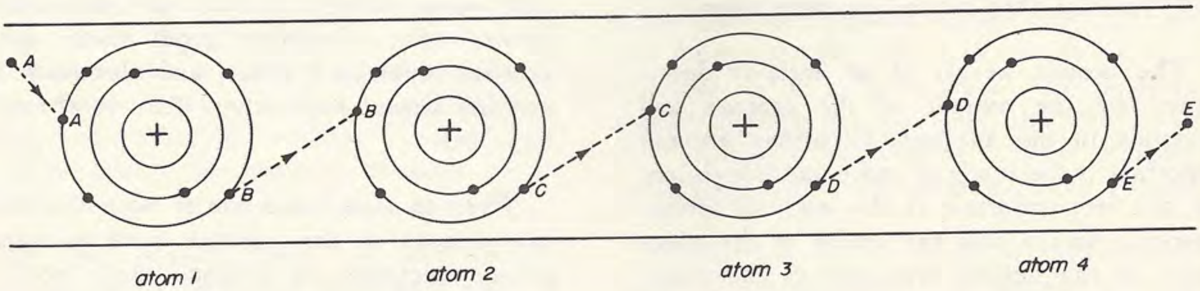


Fig. 4-4

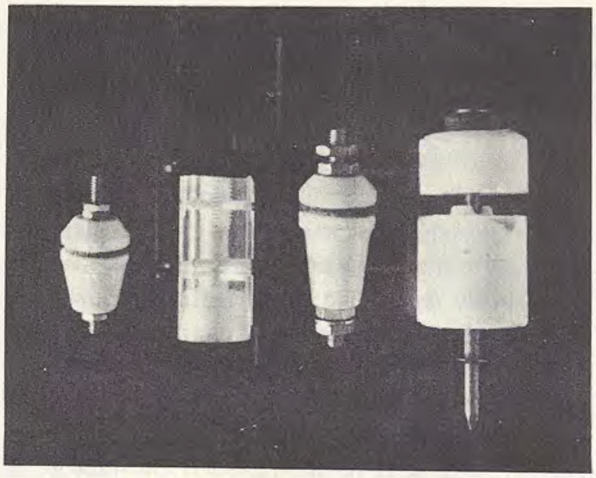


Fig. 4-5

is another kind with which you are probably familiar. It is called *static electricity*, which means electricity at rest. At times, when you comb your hair, you produce a charge of electricity on the comb. You can prove that it is there by using the charged comb to attract small bits of paper. A driver who slides out of his car from a nylon-covered seat may develop a charge on his body, which he discharges when he touches the ground or the handle of the car door. Until he touches the ground or the door handle, the charge on his body is static electricity. When he touches the ground or handle, electrons start moving and current results.

Suppose we rub a piece of glass with a piece of silk. The rubbing produces friction between the two surfaces, and electrons are wiped from the glass to the silk. The glass is left with a deficiency of electrons, and the silk with an excess of electrons. We say that the glass is positively charged and the silk is negatively charged. Since the number of electrons removed from the glass equals the number received by the silk, the two bodies are equally and oppositely charged. If we place their surfaces together again, the electrons eventually return to the glass from the silk. Charged bodies always seek to regain equilibrium or neutrality. All that is needed is a conducting path.

If we give a glass rod a positive charge by rubbing it with a silk cloth, we can attract small particles, such as paper, with *either* the glass or the silk. The paper particles have an equal amount of protons and electrons, and so are neutral. The glass has a deficiency of electrons, and is positively charged. As a result, the glass looks positive to the paper and the paper looks negative (less positive) to the glass. Since they are unlike, they attract each other. In much the same way, the silk looks negative to the paper and the paper looks positive (less negative) to the silk. Since they are unlike, they also attract each other.

If we suspend a positively charged glass rod, as shown in Fig. 4-6*a*, and bring another positively charged rod near it, the glass rod will turn away, as shown by the arrow. Having like charges, the rods repel each other. If, however, the positively charged rod is approached by a negatively charged rod, the two will attract each other, as shown in Fig. 4-6*b*, since unlike charges attract. The force of attraction decreases as the distance between the charges increases, and increases as the distance between them decreases. In other words, the nearer they are to each other, the greater is the force that is exerted.

We normally show the field surrounding the charged body by lines, as shown in Fig. 4-6*c*, *d*, and *e*. We call these *lines of force*, and we show them leaving a negatively charged body The direction is the same as that which would be travelled by a negative charge if it were placed in the electric field between two unlike charges. These lines of force do not actually exist, but they give us a convenient way of showing the force and the direction of an electric field of force.

In later lessons, you will learn more about electric fields and will discover how important they are to your study of radio and TV theory.

4-6. ELECTRIC FIELD

If during a football game, the ball should suddenly take off and sail over the goal posts, you would know that it took force acting upon the ball to send it over the posts. It would not

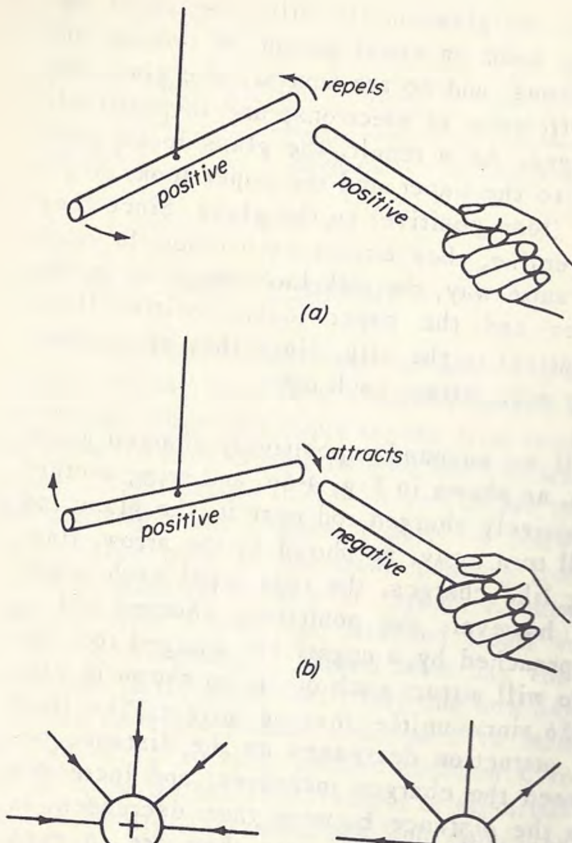


Fig. 4-6

matter that you might not have seen somebody's foot or arm send the ball on its way; you would know that the ball could not take off by itself. In much the same way, the fact that two charged bodies have an effect upon each other – that they can attract without actually touching each other – that there must be some force acting them, even though we cannot actually

The region surrounding a charged affected by this force. So, we call thi the *electrostatic field*, or even more the *electric field*. The electric field, th is the region surrounding a charged bo is affected by the charge. Any charge that enters the field will be acted upon force. For example, an electron enter electric field will be attracted if the ch positive and will be repelled if the ch negative.

4-7. CURRENT FLOW WITHOUT A DUCTOR

Current can flow without a conductor certain conditions. We can see this i action of an electron tube. If most of th is taken out of a glass tube in which are two electrodes – a filament and a pla and the filament is heated sufficiently, filament gives off electrons. If the plat positively charged, electrons will flow the filament to the plate without a conduc This is shown in Figure 4-7. The actio the batteries in producing these charges be studied later in the course.

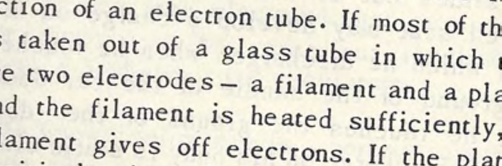


Fig. 4-7

4-8. DIRECTION OF CURRENT FLOW

We have learned that when a body has a deficiency of electrons, it is said to be positively charged. When a body has an excess of electrons, it is said to be negatively charged. If we permit the positively charged body to touch the negatively charged body, or if we place a conductor between them, electrons will travel from the negatively charged body to the positively charged body. Such a flow of electrons is called a current. The flow of electrons is always from negative to positive. Figure 4-8 shows a lamp connected to a battery. The positive terminal of the battery is marked with a plus (+) sign and the negative terminal is marked with a minus (–) sign. The arrows show that the electrons will flow from the negative terminal of the battery, through the lamp, to the positive terminal of the battery. (In the battery, something similar to the electron flow occurs from the positive terminal to the negative terminal, but this is a special condition. In all outside circuits, the electrons flow from negative to positive.)

Before the electron theory was developed, however, scientists believed that current flow in the circuit was from the positive terminal of the battery to the negative terminal, and from negative to positive within the battery. This current flow is referred to as the *conventional* current flow. For many years, servicemen have been following this theory in tracing circuits, and many books have been written using this older idea of current flow. However, as long as we remember that *electrons* flow from negative to positive, we shouldn't become confused.

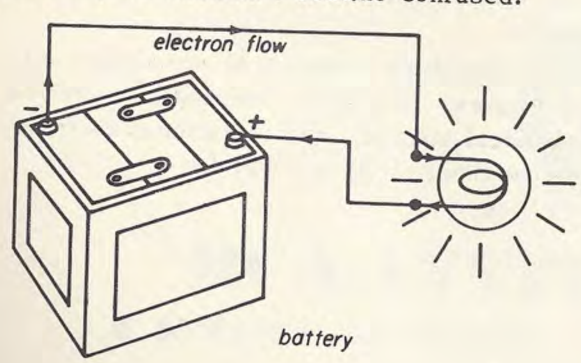


Fig. 4-8

4-9. DIFFERENCE IN POTENTIAL

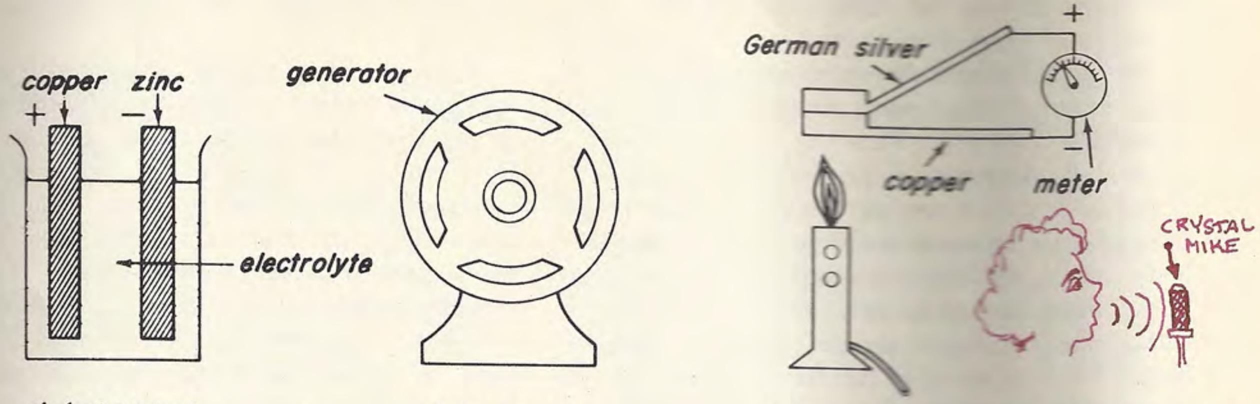
When a difference in charge exists between two bodies, a force or pressure tends to equalize the charge between them. That is, when an excess of electrons exists, the electrons try to flow toward some point where there are fewer electrons. The force that tends to make electrons travel through a conductor toward a positive charge is called *emf* (electromotive force), potential difference, or voltage. No matter what it is called, it is electrical pressure. The unit of electrical pressure is the *volt*. An exact definition of the volt is given in Theory Lesson 5.

4-10. SOURCES OF ELECTRICITY

While we can produce an electrical charge by rubbing glass with silk, or by rubbing hard rubber with fur, it would be difficult to produce large quantities of electricity by such methods. Three practical methods for producing electricity in quantity are: chemical, magnetic, and thermal, and mechanical.

The *chemical* method (see Fig. 4-9*a*) is used in both "dry" and "wet" batteries. In either case, two different metals, such as copper and zinc, or nickel and iron, are placed in a container containing a solution called an *electrolyte*. When a conductor is connected to the battery terminals, a difference in potential is produced, which results in a current flow. (How batteries work is the subject of Theory Lesson 5.) Because batteries are a rather expensive source of electricity, their use in radio usually is limited to portable equipment, such as portable radios, hearing aids, portable amplifiers, etc.

The *magnetic* method of producing electricity (see Fig. 4-9*b*) is used in generators. These are driven by gasoline or diesel engines, steam turbines, water wheels, or windmills. This way of producing electricity is the most economical and widely used. Generators are discussed in Theory Lesson 12.



(a) chemical (b) magnetic (c) thermal (d) MECHANICAL

Fig. 4-9

Producing electricity by the *thermal* method requires the use of two different metals. Figure 4-9*c* shows two metals, German silver and copper, joined together. The other ends are shown connected to a meter. When heat is applied to the point at which the metals are joined, a difference in potential is produced at the other ends, and the meter will show that a current is flowing. Such a device is called a thermocouple. The amount of voltage produced by this method depends upon the metals used and the heat applied. Usually, only small amounts of electricity are produced. The chief application of the thermal method is in the measurement of high-frequency currents and the measurement of very high temperatures. However, during World War II many people in Britain used a thermocouple device heated by charcoal or wood to generate electricity for their radios. In this way, even when electric power plants were bombed, they could still operate their radios.

4-11. SUMMARY

To understand the lessons to come, you must know and remember the following things:

1. Atoms, in their normal state, have as many protons as electrons and are therefore electrically neutral.

2. Some metals, particularly silver and copper, have many free electrons and are therefore good conductors of electricity.

3. Other materials, such as glass, mica, and rubber, have few free electrons and are therefore good insulators.

4. The law of charges states that like charges repel each other and unlike charges attract each other.

5. A positively charged body is one that has a deficiency of electrons (fewer electrons than protons).

6. A negatively charged body is one that has an excess of electrons (more electrons than protons).

7. When a difference in potential exists in a battery or a generator or between two charged bodies, and a conducting path completes the circuit, an electric current will flow. This means that the electrons will drift toward the positive (or less negative) charge.

8. The main sources of electricity are: generators (magnetic method), batteries (chemical method), and thermocouples (thermal method). and crystals (mechanical method)

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 4

ELECTROSTATIC EXPERIMENTS

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

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

Experiment Lesson 4

OBJECT

The object of the experiments in this lesson is to confirm the following statements made in Theory Lesson 4.

1. All substances in their natural state, with no pressure applied to them, are electrically neutral in charge.

2. It is possible to produce a positive or negative charge by rubbing one substance with a different substance.

3. Like charges repel each other and unlike charges attract each other.

INFORMATION

To prepare for these experiments, read and study Theory Lesson 4. The proper time to do these experiments is when you are fairly sure that you understand the Theory Lesson. If, during an experiment, something puzzles you, go back to the Theory Lesson and look for the answer there.

These experiments are based on materials you have right in your own home. They are best performed in cool, dry weather. Otherwise, weather conditions may make it almost impossible to produce enough static electricity to do them. For, when the air contains a lot of moisture, a charge may leak off as fast as it is produced. There's nothing anyone can do about it.

METHOD

Weather permitting, the object of this lesson will be achieved by:

1. Testing materials to find out if any charge exists *before* an attempt is made to produce one. This is done by trying to attract small particles or a paper ball with a material in its natural state.

2. Testing the same materials for the presence of a charge *after* an attempt is made to produce a charge.

3. Producing like charges and unlike charges to test for repulsion and attraction. This is done by charging two like bodies, and later, two unlike bodies – suspending one of them so that it may move freely, approaching it with the other, and noting the result.

PART ONE

EQUIPMENT NEEDED

Neon bulb (from Kit 2)

A grounded surface

A rug or carpet

The grounded surface may be a cold-water pipe or faucet, a steam or hot-water radiator, an indoor water-pump spout, a radio ground lead, or some other metal conduit or pipe that is connected to the ground.

EXPERIMENT 4-1

To charge your body and discharge it to ground.

Procedure.

Step 1. Locate the nearest grounded surface. If possible, it should be in a room with a carpet or rug on the floor. From now on, we'll call it the *ground.*

Step 2. Stand near the ground, without touching it, for one minute. This is to give your body a chance to get rid of any charge it may have picked up on the way to the ground.

Step 3. Now touch the ground with your finger. When you touch ground, you should feel nothing but the metal surface of the ground.

Step 4. Walk back and forth across the carpet or rug, dragging your feet a little, and approach the ground.

Step 5. Immediately touch the ground. If the weather is favorable, you should feel a slight tingle as your finger touches the metal. If you do, repeat the experiment. This time, watch closely and see if you don't see a small flash or spark as the electric charge leaves your finger and is grounded.

EXPERIMENT 4-2

To charge your body and discharge it through a neon bulb to ground.

Information. In Experiment 4-2, you will use the small neon bulb that was sent to you in Kit 2. Be careful in handling this neon bulb, because it is easily broken. Later, you will learn why it is that neon bulbs glow. Right now, it is a little too soon to talk about the theory involved. However, it is very important that you know that about 75 volts of electrical pressure between the two leads of the neon bulb are required for it to glow. Therefore, if the neon bulb glows in the experiment that you are about to perform, you can be sure that the difference in potential that exists between your body (which you will charge electrically) and ground is at least 75 volts.

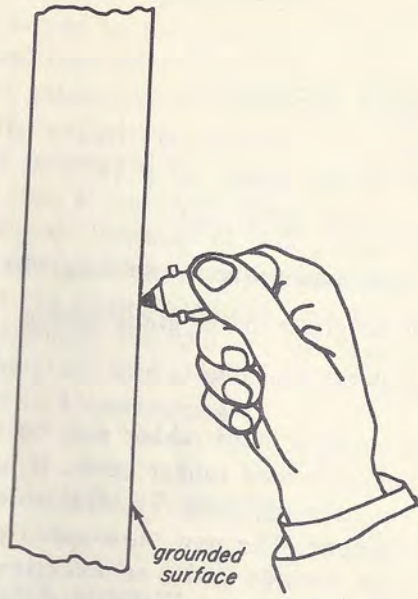


Fig. 4-1

CAUTION. Do not connect the terminals of your neon bulb across the terminals of any electrical outlet in your home or shop. If you do, you may burn it out. Later in this course, you will need it in order to perform other experiments.

Procedure.

Step 1. Make sure that your body is not charged by touching the metal surface of the ground.

Step 2. Charge your body as you did in Experiment 4-1.

Step 3. Hold the neon bulb by the metal band, as shown in Fig. 4-1. Touch the grounded surface with the contact on the bottom, and, at the same time, look at the neon bulb. If the weather and atmospheric conditions are favorable, and you have been able to charge your body, the neon bulb will glow for a moment. If you are not successful the first time, try again. If the weather is moist and humid, you may not be able to do this experiment. Wait for the first cool, dry day. Then conditions for performing this experiment will be better. Try this experiment then; you may be more successful.

PART TWO

EQUIPMENT NEEDED

Piece of silk about 12" x 12"

Piece of fur or flannel

Piece of hard rubber or sealing wax

Piece of glass rod or glass tubing

Small piece of paper

The length of hard rubber may be a hard rubber rod or a hard rubber comb. If no hard rubber or sealing wax is available, use plastic instead. The new slow-speed plastic phonograph records make an excellent substitute for hard rubber or sealing wax. A small glass bottle, thoroughly dry, may be used instead of a glass rod or glass tubing.

EXPERIMENT 4-3

To attract small paper particles with charged materials.

Procedure.

Step 1. Cut the piece of paper into very tiny pieces (1/8" squares or smaller). Place some of the paper particles on a dry, nonmetallic surface, such as a wooden table top, a sheet of linoleum or glass, or a sheet of paper.

Step 2. Touch the paper particles with the hard rubber. Nothing should happen.

Step 3. Touch the paper particles with the glass. Nothing should happen.

Step 4. Rub the piece of hard rubber (or the substitute you're using) with the piece of fur or flannel, as shown in Fig. 4-2.

Fig. 4-2

Step 5. Immediately bring the free end of the hard rubber close to the paper particles, but do not touch them. Either some of the particles will be attracted to the rubber and jump up to meet it, or some of the paper particles will stand on edge, but will not quite make the jump to the hard rubber. Of course, there is a third possibility – that nothing happens. If so, try again. If it doesn't work the second time, try a piece of plastic – one of the new plastic phono records, if possible.

Step 6. Now rub the glass briskly with the piece of silk.

Step 7. Immediately place the glass near a fresh supply of the paper particles and see what happens. The particles should be attracted to the glass.

EXPERIMENT 4-4

To learn what attraction oppositely charged bodies have on each other.

Procedure.

Step 1. Rub the hard rubber with the fur and directly touch some of the paper particles with the rubber. In rubbing the hard rubber with the fur, electrons are wiped off the fur and onto the hard rubber. As a result, the hard rubber has an excess of electrons and so is negatively charged. When the negatively charged rubber touches the paper particles, the particles become negatively charged by *conduction* (by actual contact).

Step 2. Next, rub the glass with the silk and approach the same paper particles with the glass. The silk wipes off electrons from the glass and leaves the glass positively charged. Approach the negatively charged paper particles with the positively charged glass. The paper particles should jump up to meet the glass more readily than they did in Step 7 of Experiment 4-3, as shown in Fig. 4-3.

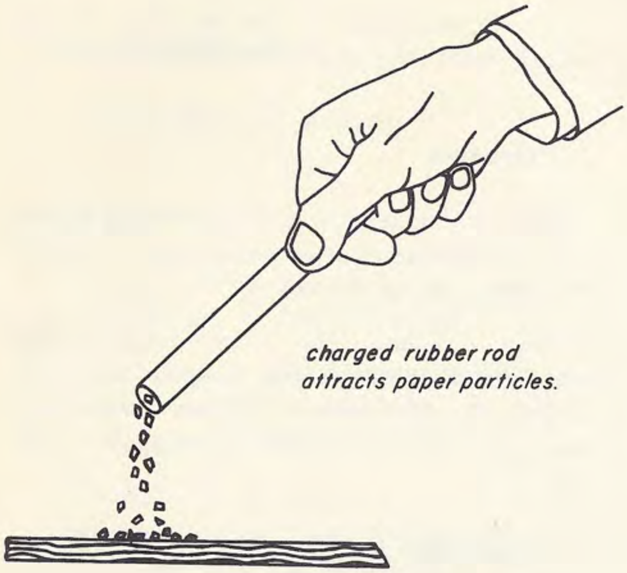


Fig. 4-3

Discussion. The reason that the positively charged glass attracts the paper particles more readily in Experiment 4-4 than in Experiment 4-3 is not hard to find. Let's think it out.

First of all, in Experiment 4-3, when the negatively charged hard rubber approaches the paper particles, the particles are electrically neutral (they are not positively or negatively charged). So, the amount of attraction between the hard rubber and the paper particles depends upon the amount of charge on the hard rubber (on the amount of electrons that were wiped off the fur onto the hard rubber). When the glass was rubbed with silk in Step 6 of Experiment 4-3, electrons were wiped off the glass, leaving it positively charged. Then, when the positively charged glass approached the paper particles, the paper was neutral, so that the attraction that the glass had upon the paper particles depended on the amount of positive charge on the glass (the number of electrons wiped off the glass by the silk). However, in Experiment 4-4, when the paper particles were charged by the hard rubber (by conduction) and then approached by the positively charged glass, the difference in charge between the negatively charged paper particles and the positively charged glass was much greater than it was when the paper particles were neutral. Because of this greater difference in charge, there was a greater attraction between the paper particles and the glass. This accounts for the greater ease with which the glass was able to attract the paper particles in Experiment 4-4.

PART THREE

EQUIPMENT NEEDED

Same as in Part Two, with the addition of some silk thread and a paper napkin or a piece of paper tissue.

EXPERIMENT 4-5

To charge two adjacent paper balls by conduction and see the effect that they have upon each other.

Procedure.

Step 1. Roll two 3" x 3" pieces of tissue paper into two tight balls. Tie each of these paper balls to a two-foot length of silk thread.

Step 2. Hang one of the balls from some convenient place, where it may swing freely without touching a wall or other object.

Step 3. Charge the hard rubber with the fur.

Step 4. Immediately approach the suspended paper ball with the charged hard rubber. The ball should be attracted to the hard rubber, as shown in Fig. 4-4. Charge the ball by letting the hard rubber touch it.

Step 5. Recharge the hard rubber and again approach the ball. The ball, being negatively charged, should now be repelled.

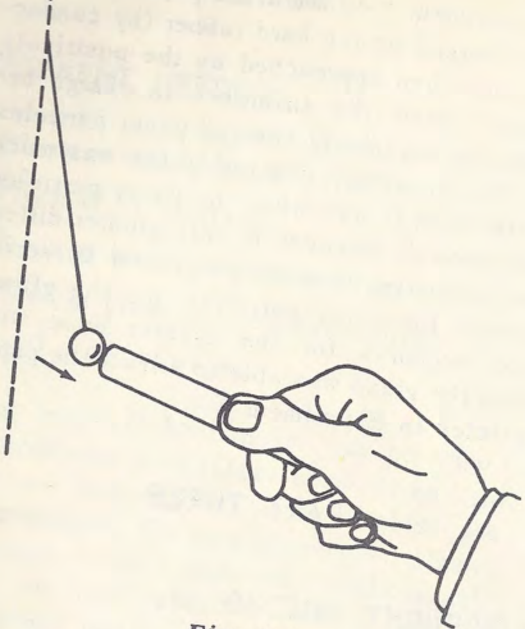


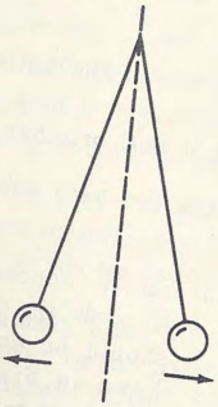
Fig. 4-4

Step 6. Hang the second paper ball so that the two balls are about an inch apart.

Step 7. Recharge the hard rubber and charge the second paper ball by touching it with the rubber. The two balls, each negatively charged, should repel each other, as shown in Fig. 4-5.

Step 8. Charge the glass rod with the silk.

Step 9. Charge one of the paper balls with the charged glass. Now one of the balls is positively charged and the other is still negatively charged. They should attract each other. If the experiment doesn't work out the first time, try again.



Two identically charged paper balls repelling each other

Fig. 4-5

EXPERIMENT 4-6

To see the effect of placing a like charge on two adjacent pieces of rubber.

Procedure.

Step 1. Suspend one piece of hard rubber with silk thread. Let it swing freely. Charge it with the fur or flannel.

Step 2. Charge the other piece of hard rubber and approach the suspended rubber with it. The suspended rubber should turn away, repelled by a like charge. See Fig. 4-6.

Discussion. In Part Three, the law of charges, which states that like charges repel each other and unlike charges attract each other, is confirmed. In this part, weather permitting, you found that when both paper balls were charged negatively, they repelled each other; and that when one was negatively charged and the other was positively charged, they attracted each other.

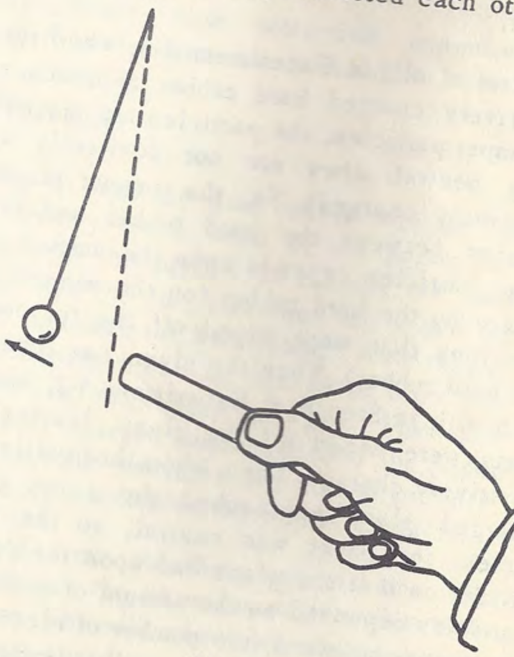


Fig. 4-6

PART FOUR

EQUIPMENT NEEDED

One toy balloon.

EXPERIMENT 4-7.

To charge a toy balloon.

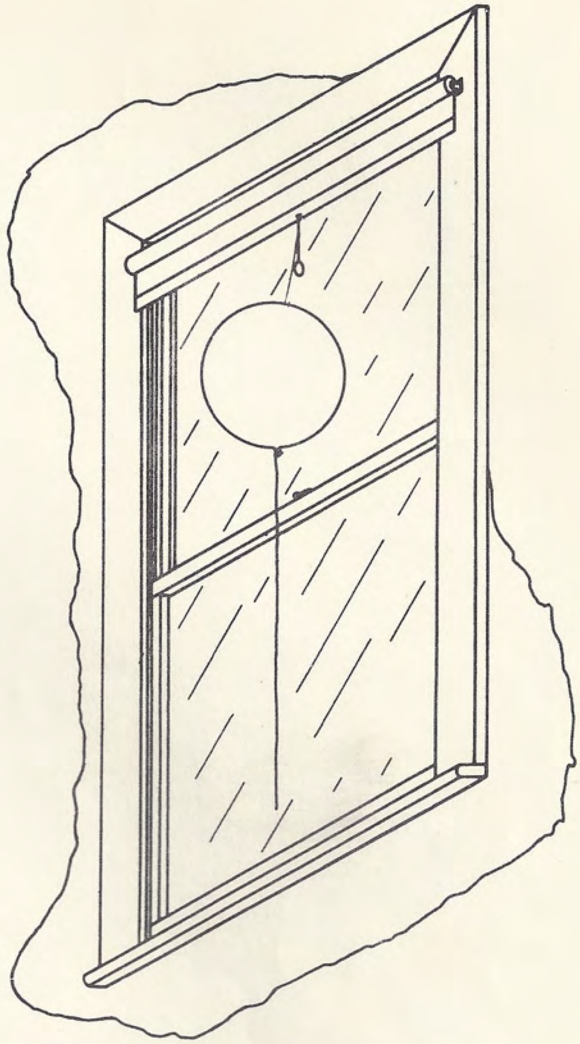
Procedure.

Step 1. Blow up the balloon and tie it to prevent the air from escaping.

Step 2. Rub the balloon against a dry window pane. The balloon will be attracted to the glass and stay there.

Step 3. Or, and this is a good one to remember for party decoration, rub the balloon briskly with wool. It will stick to a wall and stay there.

Discussion. In the experiment where the toy balloon is rubbed against a dry window pane, the glass and the balloon became oppositely charged and so were attracted to each other. From the experiments discussed in this lesson, can you think of a way by which you could tell whether the balloon becomes positively charged or negatively charged?



Charged balloon attracted to window pane

Fig. 4-7