INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 11 TO 20

2RK-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

PIONEER HOME STUDY RADIO SCHOOL

NRI

COURSE IN PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

WHAT'S YOUR HURRY?

Youth is eager and impatient. It seeks to achieve success at a single bound. But older people know from cruel experience that success is not acquired in a minute, nor a week, nor a month. If it were that easy to secure, every one would be a President, a Supreme Court Justice, or a millionaire captain of industry, and the world would be like a navy in which every sailor is a captain!

"Learn to walk before you run" is good grandmotherly advice. The worst type of ignorance is *not knowing how much there is to know.* Just because you have attained the first step in your climb to success, don't get the idea you can skip all the other steps.

Build gradually that ladder of knowledge and experience by which you will rise in radio. Be like the postage stamp, which sticks to one thing until it gets there, and you'll be able to stay at the top when you do arrive.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1949 Edition

THIS EXPERIMENTAL MANUAL IS A PART OF THE N. R. I. COURSE WHICH TRAINS YOU TO BECOME A RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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Instructions for Performing Radio Experiments 11 to 20

Introduction

IN THE design, construction and repair of radio apparatus, circuits are highly important. You have already studied many different types of circuits in your regular course, and have learned that every circuit must have three things: *1. A source of voltage; 2. A load; 3. A transmission system* (either two simple wires or a complex arrangement of radio parts) *which connects together the source and load.*

In the next ten experiments, you will work with real radio circuits and actually demonstrate for yourself their characteristics. In one experiment, you will prove that electrons flow in a definite direction between the source and the load in a d.c. circuit. In another experiment, you will increase the source voltage and see that this makes the current increase. You will also increase the resistance in a circuit, and prove that the current decreases exactly as Ohm's Law says it will.

Four entire experiments in this manual are devoted to vacuum tube circuits. You will actually see for yourself that current can flow through the vacuum inside a tube when one electrode is heated and another electrode is positively charged with respect to the heated electrode. You will also perform an experiment which shows how a vacuum tube can control the flow of electrons in a circuit. By working with vacuum tube circuits right from the start, you will become accustomed to thinking in terms of electron flow, and will soon find yourself using vacuum tubes as guides to tell the direction of electron flow in any circuit.

Contents of Radio Kit 2RK-1

The parts included in Radio Kit 2RK-1 are illustrated in Fig. *1* and listed in the caption underneath. Check against this list the parts which you received, to be sure you have all of them.

If any part is obviously defective or has been damaged during shipment, please return it to the Institute *immediately* for replacement.

RMA Color Code for Resistors

Most of the fixed resistors included with NRI radio kits are marked according to the standard Radio Manufacturers' Association (RMA) color code, in addition to having the ohmic value printed on the body of the resistor. Furthermore, resistors used in commercial radio equipment are often identified only by these color code markings. (Some radio set manufacturers used private color codes for resistors. These resistors must be checked by actual measurement.) The RMA color code is presented in Fig. *2* for your convenience in referring to it while you are carrying out these experiments.

Tolerances. The standard tolerance observed by manufacturers of carbon or metalized resistors is 20%. This means that the actual value of a resistor may be as much as 20% higher or 20% lower than the rated value. For example, in the case of a 1,000-ohm resistor, the standard 20% tolerance comes to 200 ohms, and the

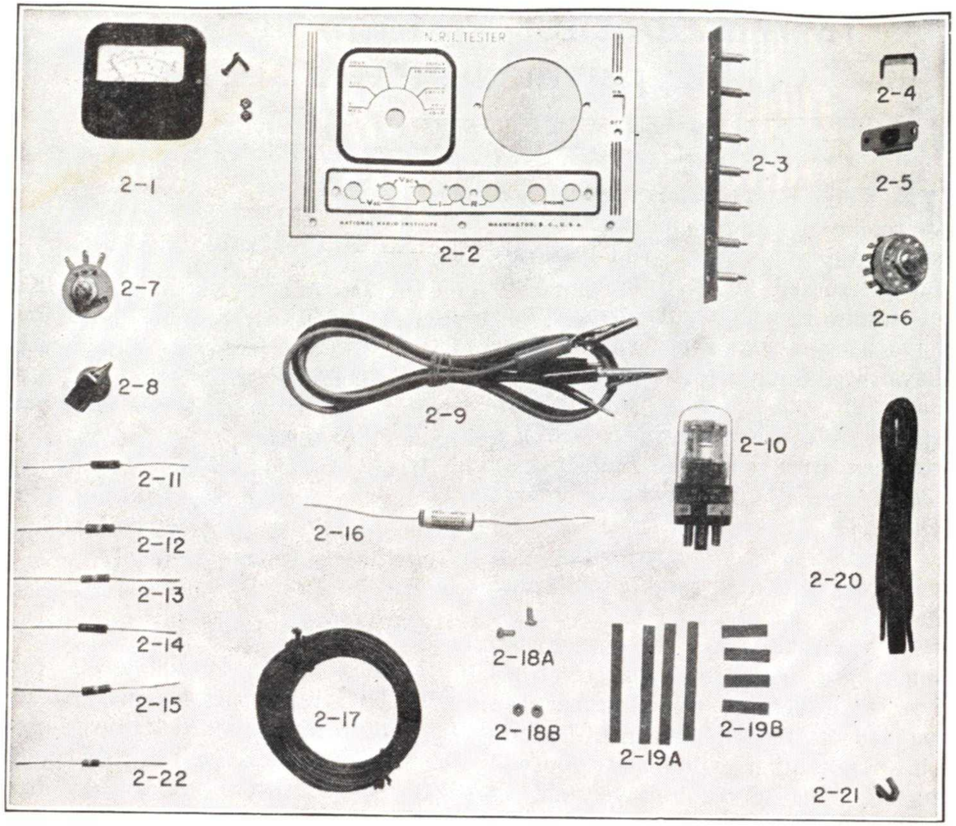


FIG. 1. The parts included in Radio Kit 2RK-1 are pictured above, and are identified in the list below. Note that the first numeral in each part number is 2; this enables you to identify these parts immediately as having been supplied to you in Radio Kit 2RK-1. When an experiment calls for a part having 1 as its first numeral, you know immediately that the part was supplied to you in Radio Kit 1RK.

Part No.	*Description*
2-1	One 0-3-ma. milliammeter with special scale and zero-readjusting knob at rear. Two mounting screws and two nuts are included with the meter.
2-2	Front panel for NRI Tester.
2-3	One 7-jack strip.
2-4	One U-shaped shorting piece for phone jacks.
2-5	One slide-type ON-OFF power switch.
2-6	One 6-position rotary selector switch.
2-7	One 1,000-ohm wire-wound potentiometer.
2-8	One bar knob for the selector switch.
2-9	**One pair of test leads** (one red and one black lead) with probes and alligator clips.
2-10	**One type 1C5GT vacuum tube. (This tube is sometimes marked 1C5G or 1C5GT/G.)**
2-11*	One 6.8-megohm, ½-watt resistor with 5% tolerance (color-coded blue, gray, green, gold).
2-12	One 3-megohm, ½-watt resistor with 5% tolerance (color-coded orange, black, green, gold).
2-13*	**One .24-megohm, ½-watt resistor with 5% tolerance** (color-coded, red, yellow, yellow, gold.) (This is the same as Part *1-14,* so you can use either *2-13* or *1-14.*)
2-14*	One 910-ohm, ½-watt resistor with 5% tolerance (color-coded white, brown, brown, gold).
2-15	One 100-ohm, ½-watt resistor with 5% tolerance (color-coded brown, black, brown, gold).
2-16	**One .005-mfd., 600-volt paper condenser.**
2-17	One 25-foot roll of push-back hook-up wire.
2-18A	Two ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
2-18B	**Two cadmium-plated hexagonal nuts for 6/32 screws.**
2-19A	Four ¼-inch wide, 2½-inch long tinned copper strips.
2-19B	Four ¼-inch wide, 1-inch long tinned copper strips.
2-20	One 45-inch length of black lace for fastening tester batteries to chassis.
2-21	One grid clip.
2-22*	One .22-megohm, ½-watt resistor with 20% tolerance (color-coded red, red and yellow).

* These values are the new, post-war "standard" values and are therefore slightly different from the 6.7, .25, .2-megohm, and 900-ohm values shown in the various tables and diagrams.

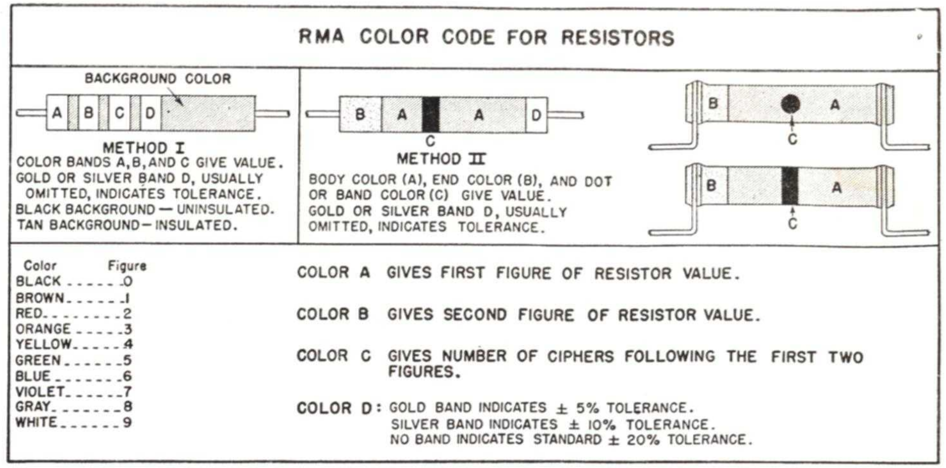


FIG. 2. The two methods being used for marking resistors according to the standard R.M.A. Color Code are given here.

When a color band is missing in non-insulated (black background) resistors marked according to Method I, assume that the color of the missing band is black.

When end color B, or dot or band C, is missing in a resistor marked by Method II, the missing marking is the same as body color *A;* thus, an all-red color-coded resistor would be 2,200 ohms.

Note that with Method I markings the color bands are all equal in width, while with Method II marking on resistors having leads coming straight out from the ends, the color bands are of different widths; this serves as a clue for telling which method of marking is employed. Resistors with side leads (shown at the right above) are not insulated.

resistor may therefore have a value anywhere between 800 ohms and 1,200 ohms. No special tolerance markings are used when a resistor has standard 20% tolerance.

In some radio circuits, better accuracy is required for resistors. With 10% tolerance, a 1,000-ohm resistor would be somewhere between 900 ohms and 1,100 ohms. When resistors with 10% tolerance are marked according to Method *I* in Fig. *2,* they will have a *silver* band at *D.*

With 5% tolerance, the range of variation would be between 950-ohm and 1,050 ohms for a rated 1,000-ohm resistor. When resistors with 5% tolerance are marked according to Method *I* in Fig. *2,* they will have a *gold* band at *D.*

Radio servicemen are rarely concerned with resistor tolerances because the standard tolerance of 20% is entirely satisfactory for the great majority of circuits. In the NRI Tester which you will soon build, however you will use some resistors having 5% tolerance.

Insulated Resistors. When the outer covering of a resistor is an insulating material, we have what is known as an *insulated resistor.* When marked according to Method *I* in Fig. *2,* you can identify these by the fact that they have a *tan* background color. These resistors may safely be used in contact with the chassis or other parts.

When there is no insulating covering on a ceramic fixed resistor, we have what is known as a *non-insulated* resistor. When marked according to Method *I* in Fig. *2,* these have a *black* background color. Non-insulated resistors should not be allowed to touch other parts or wires.

Many of the resistors furnished to you in NRI radio kits are of the insulated type, but nevertheless it is always good practice to position resistors so that they do not touch other parts.

Batteries Needed

The batteries needed for the ten experiments in this manual and for construction of the NRI Tester are pictured in Fig. *3*. Instructions for ordering these batteries have already been sent to you.

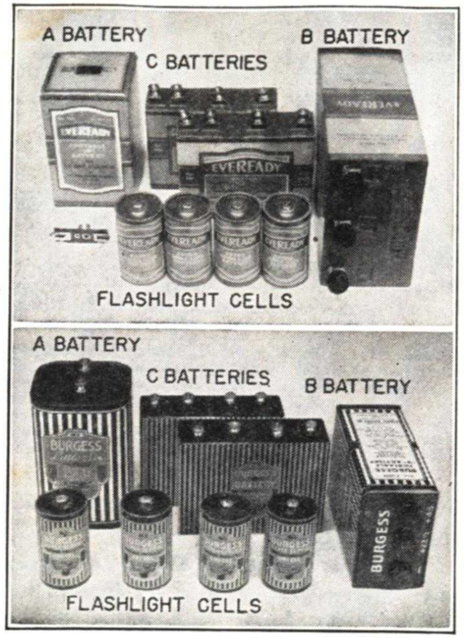


FIG. 3 The only batteries you need for Experiments 11 to 20 in this manual and for the NRI Tester are four standard No. 2 (large size) flashlight cells, one 1½-volt A battery, one 45-volt B battery and two 4½-volt C batteries. These can be the Eveready or Burgess units shown here and specified below, or any other makes having exactly the same dimensions and terminal arrangements.

The Eveready battery kit consists of the following:

One type 742 1½-volt A battery.
One type 1024 plug-in adapter for A battery.
One type 762-S 45-volt B battery.
Two type 761-A 4½-volt C batteries.
Four type 950 flashlight cells with removable paper jackets.

The Burgess battery kit consists of the following:
One type 4FH 1½-volt A battery.
One type 5308 45-volt B battery.
Two type 2370 4½-volt C batteries.
Four No. 2 flashlight cells with removable paper jackets.

Battery kits purchased from National Radio Institute will also include a terminal identification card for C batteries.

If you followed the instructions given in the battery folder accompanying your first radio kit (1RK), you will already have a kit of batteries purchased from National Radio Institute, or from any firm handling radio parts. If for any reason you have not yet obtained your batteries, *order them immediately* because you will need them for the experiments in this manual. Write to us for a price quotation if you did not get a battery folder.

Batteries are required for **every** experiment in this second manual of your practical demonstration course, so order your batteries immediately (either from NRI or from a radio supply firm) if you have not already done so.

INSTRUCTIONS FOR EACH EXPERIMENT

1. **Read the entire experiment, giving particular attention to the discussion.**
2. **Perform each step of the experiment and record your results.**
3. **Study the discussion and analyze your results.**
4. **Answer the report statement for the experiment It will always be on the last page of the manual.**

EXPERIMENT 11

Purpose: **To demonstrate that a d.c. voltage source has polarity.**

Step 1. To provide convenient soldering terminals for the four flashlight cells, take one of the 2½-inch long tinned copper strips (Part *2-19A)*, and make a rounded right-angle bend ¾ inch from one end with long-nose pliers. Now hold one of the cells in your left hand and push the zinc container almost entirely out of the cardboard cylinder with the thumb of your right hand, as shown in Fig. *4A*. Insert the long end of the bent strip between the cardboard housing and the zinc case of the cell, as shown in Fig. *4B*. This can be done most easily when the zinc can is just about ready to come out of the cardboard cylinder. Be sure the strip is against the zinc can, not between layers of paper. Push the strip down until the horizontal part of the strip

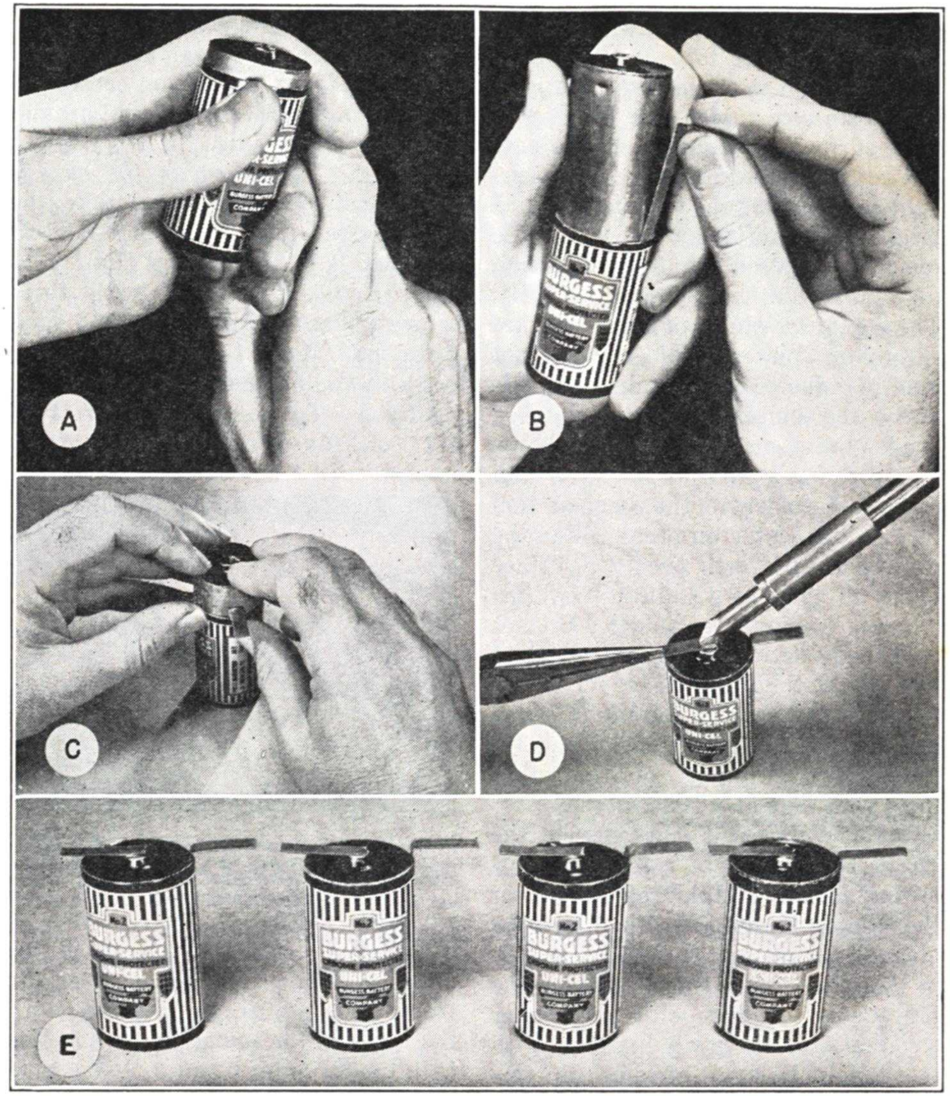


FIG. 4. Steps in providing the four 1½-volt flashlight cells with convenient soldering terminals.

is about ⅛ inch above the top of the cardboard cylinder, then push the zinc can carefully back into its housing by pressing evenly with the fingers of both hands as shown in Fig. *4C*.

In the same way, bend each of the other 2½-inch long tinned copper strips, and insert one against the zinc can of each of the other three cells.

Although the copper strips are tinned during manufacture, this original coating of solder is quite thin and is sometimes covered with grease or oxides. Additional tinning of areas to which connections will be made takes only a few minutes, and greatly simplifies future work with the strips.

Tin each of the 1-inch long strips (Part *2-19B)* on one side for about ¼ inch from one end, by grasping a strip with long-nose pliers and holding it over a flat face of the heated soldering iron in its holder, then rubbing rosin-core solder over the uppermost surface of the strip at one end.

Tin the center terminal of a flashlight cell by filing the top surface until bright (be careful not to let the file touch the exposed rim of the zinc can, for that would short-circuit the cell). The center terminals of some cells are chromium plated; solder will not readily adhere to chromium, so file away the chromium layer until a bright brass or copper color shows. Apply the heated soldering iron and rosin-core solder to the cleaned surface of the center terminal. Slide the iron back and forth over the surface to tin all parts of it uniformly with a minimum amount of solder. Do not hold the soldering iron on the terminal any longer than necessary, for excessive heat can shorten the life of a dry cell. In the same way, clean and tin the center terminals of the other three cells, one at a time.

Solder a tinned 1-inch strip to the center terminal of a cell in the following manner: Hold the strip over the center terminal with long-nose pliers in the manner shown in Fig. *4D*, so that the freshly tinned area on the strip is in contact with the center terminal and the strip lines up with the 2½-inch strip already on this cell. The two strips then project on opposite sides of the cell. Apply the heated soldering iron to the strip just long enough to fuse together the solder on the strip and the terminal. Hold the strip rigid until the solder hardens. *Do not let either the pliers or the tinned copper strip touch the metal rim of the cell;* bend the strip upward if necessary.

Solder a 1-inch strip to the center terminals of each of the other three cells in the same way. Your four cells should now appear as shown in Fig. *4E*. If you desire, you can round off the sharp corners of these terminal strips with your file.

Step 2. To assemble the chassis and panel for future use, take the NRI Tester front panel (Part *2-2)* and bolt it to the chassis (Part *1-11* from Radio Kit 1RK) with three screws (Part *1-9A* or *2-18A*) and three nuts (Part *1-9B* or *2-18B) exactly* in the manner shown in Fig. *5*.

Step 3. To mount the meter (Part *2-1) on the panel for convenience*

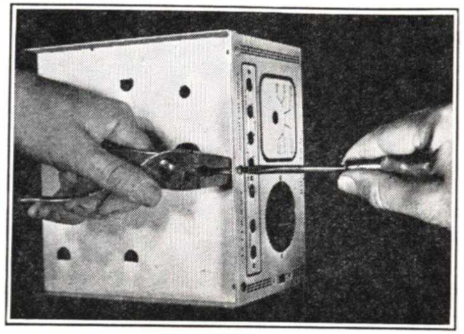


FIG. 5. Fasten the front panel to the chassis exactly as shown here. Use a medium-size screwdriver to tighten each screw while holding its nut with ordinary pliers.

in making measurements, place the meter in hole *q* (see Fig. *6*) from the front, and adjust its position until the holes in the meter frame coincide with panels holes *r* and *s*. Now take the meter mounting screws (these are in the small envelope in the meter box), insert them in meter mounting holes *r* and *s* from the front of the panel, then place the nuts on these screws at the back of the panel. Tighten first with the fingers, then with long-nose pliers and a screwdriver. When looking at the back of the panel now, the meter will appear as shown in Fig. *6*.

Step 4. To mount the 7-jack strip

(Part *2-3) on the panel,* wipe dust off both sides of the strip, hold the strip against the *BACK* of the panel (not against the printed side of the panel) in the position shown in Fig. *6*. Fasten the strip to the panel with three screws *(1-9A* or *2-18A)* and three nuts *(1-9* or *2-18B)*. There is only one position of the strip in which the three mounting holes on the strip and panel will coincide. Shift the strip sideways slightly, if necessary, so that the jack openings showing on the printed side of the panel are centered as well as possible in the panel holes.

On the back of the panel, directly above each jack, write its terminal number with a metal-marking crayon, exactly as shown in Fig. *6*. Keep the point of the crayon sharp by trimming it off with a pocket knife or by rubbing the crayon on scrap paper to reshape the point.

Step 5. To connect the meter to two of the jacks on the panel with temporary soldered joints for convenience in making tests, remove *one* of the nuts from the positive meter terminal (this terminal is identified by a small plus sign stamped into the meter case near the terminal), place a 13/16-inch long soldering lug (Part *1-8A*) on the meter terminal after first straightening out the lug with long-nose pliers, then replace the nut and tighten with fingers and pliers while holding the lug straight down. Mark the number *15* above this lug on the meter case with crayon. In the same way, straighten another lug (Part *1-8B)*, place it on the other meter terminal (this is the negative terminal of the meter and has no marking), and mark the number *16* above this lug on the meter case.

Now cut off a 3¼-inch length from the roll of push-back wire supplied you as Part *2-17*, push the insulation back ½ inch from each end, then form a hook in one end with long-nose pliers and hook this through the + terminal lug of the meter (lug *15* in Fig. *6)*. Push the other end of the wire through the hole in the soldering lug of jack *27* and bend the wire back on itself to form a hook. In the same way, cut a 2½-inch length of push-back wire and use it to connect lug *16* (on the — terminal of the meter) to the lug on jack *28*. Solder all four of these temporary joints now with rosin-core solder.

Step 6. To set the meter point at

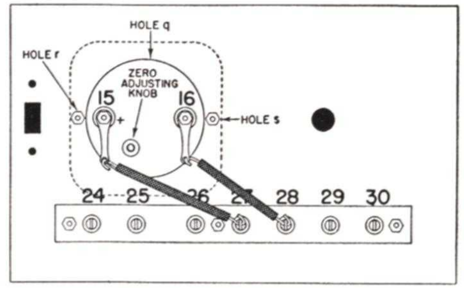


FIG. 6. *Rear* view of front panel, showing how the meter and jack strip are mounted and connected together for the experiments which are to be made before assembling the NRI Tester. The chassis is not shown in this view, but should be attached to the bottom of the panel according to instructions given in Step 2 of Experiment 11.

zero, locate the knurled zero-adjusting knob at the back of the meter (the position of this knob is indicated in Fig. *6)*. With your fingers, rotate this knob first in one direction as far as it will go, then in the other direction while watching the front of the meter, to get a general idea of how the knob controls the pointer position. After this, adjust the knob carefully while tapping the meter lightly with one finger, until the pointer is exactly at the zero line on the lowest scale of the meter (this scale is marked I_M).

Step 7. To show that the meter will read up-scale when properly connected to a voltage source, first secure the pair of test leads furnished you as

Part 2-9, and plug these into the two jacks marked *I* on the front panel; plug the red-handled probe into the *I* jack marked +, and plug the black-handled probe in the *I* jack marked —, as shown in Fig. 7. If difficulty is encountered in inserting a probe in a jack the first time, twist and wiggle the probe slightly while pushing on it, so as to loosen the spring contacts in the jack. Hold the back of the jack with one hand while doing this, to minimize the pressure exerted on the fiber jack strip.

Now attach the alligator clip of the red lead to the positive (center) terminal strip of one of the flashlight cells which you previously prepared, and watch the meter pointer while you hold the alligator clip of the black test lead on the tinned copper strip which serves as the negative terminal of this flashlight cell. As soon as you have noted the direction in which the pointer moves, open the circuit by removing one of the alligator clips, so as to avoid unnecessary drain on the cell. It is only necessary now to observe the direction in which the pointer moves; do not try to read the meter yet.

Step 8. To demonstrate that the meter will read down-scale (off-scale to the left of zero) *when improperly connected to a d.c. voltage source,* leave the test leads plugged into the panel jacks just as before, but now place the red alligator clip on the — cell terminal and place the black clip on the + cell terminal. Note the direction in which the meter pointer moves, then break the circuit by removing both alligator clips.

Discussion: The four flashlight cells which you were instructed to obtain for your practical demonstration course will be connected together in various ways to provide a variety of d.c. voltage values. The terminal strips which you place on these cells in Step 1 will greatly simplify the connecting of these cells into experimental circuits.

The important thing for you to remember in connection with these cells is that the center terminal of each cell is + (positive). The 1-inch long strip which you soldered to this center terminal thus becomes the + terminal of the cell. If you wish, you may mark a + sign on the center strip with a metal-marking crayon. The 2½-inch long strip which you inserted between the cardboard housing and the zinc case therefore becomes the — (negative) terminal.

In Steps 3, 4, and 5, you prepare the meter for use by mounting it on a vertical panel and conecting it to two of the jacks which are also mounted on this panel. When this is done, you can make connections to the meter simply by plugging your test leads into the two jacks marked *I* on the front panel. You will find that this preliminary work greatly simplifies the use of the meter during the next ten experiments.

Step 6 is intended to familiarize you with the use of the zero-adjusting knob at the back of your meter. Always tap the top of the meter lightly with the finger while adjusting the zero position of the pointer or reading low current and voltage values; the resulting slight vibration overcomes any friction which may exist at the bearings of the meter pointer.

Your meter is highly sensitive to the presence of iron, steel or any magnetic field in its vicinity. You can demonstrate this for yourself by watching the pointer while moving a pair of steel pliers or some other steel object in front of the meter.

If the meter pointer refuses to return to zero at any time even with tapping, there may be a magnetic field or magnetic material somewhere in the vicinity.* You can either re-adjust the zero-adjusting knob to compensate for this condition, or remove the offending material. When conducting experiments, keep all iron or steel tools at least 6 inches away from the meter. This seemingly peculiar behavior of your meter is entirely normal, and is an inherent characteristic of all magnetic vane type meters such as yours.

In Step 7 you connected the + terminal of the meter to the + terminal of the flashlight cell, and connected the — meter terminal to the — terminal of the flashlight cell. This is the correct polarity for connecting a meter to a d.c. voltage source, and you therefore obtained an up-scale movement of the meter pointer.

Now, since you know that the meter reads up-scale whenever the + meter terminal is connected to the + terminal of a voltage source, you can determine the polarity of any d.c. voltage source within the range of your meter. Simply connect the meter to the voltage source and note the direction in which the pointer moves. If the pointer moves up-scale, you then know that the red test lead (the + terminal of the meter) is on the + terminal of the voltage source. If the meter pointer reads down-scale, as it did when you reversed the meter connections in Step 8, you know that the meter is improperly connected. When this occurs, reverse the positions of the test clips immediately.

Do not leave the meter connected to the flashlight cell any longer than is necessary to observe the movement of the meter pointer. The meter draws a certain amount of current from the flashlight cell, and naturally you want to conserve the life of the cell.

In your fundamental course, you learned that electrons always flow *out of* the negative terminal of a d.c. voltage source, and flow *into* the positive terminal of the d.c. voltage source after they have traveled around the external circuit. You also learned that a *d.c.* meter should be connected *so electrons enter the negative terminal of the meter.* With these fundamental facts in mind, you can very easily trace electron flow in your simple circuit consisting of the meter connected across the flashlight cell. The electrons leave the — terminal of the cell, go through the black test lead, the — *I* jack and one length of hook-up wire to the meter. The electrons then enter the — terminal of the meter (marked *16*), flow through the coil of wire inside the meter, emerge from

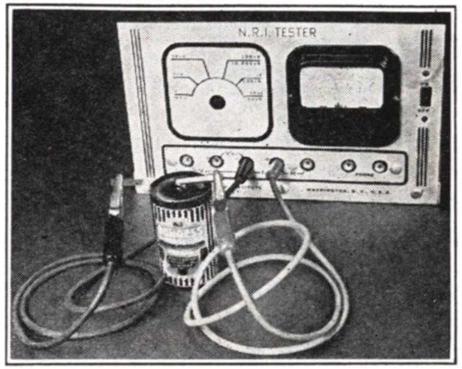


FIG. 7. Using the meter to demonstrate that a d.c. voltage source (the flashlight cell) has polarity. The meter pointer moves up-scale only when the cell is connected to the meter with proper polarity. The test leads were coiled merely to simplify taking the photograph; you will not have to bother with arranging the test leads in any particular position during experiments.

* Overloading of the meter can also cause a shift in the zero position of the pointer. This condition will usually correct itself in a short time, but you will receive instructions later for correcting the shift immediately.

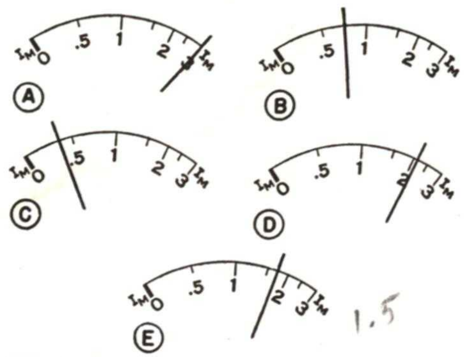


FIG. 8. Examples illustrating how to read scale I_M of your meter. The reading for *A* is 3 ma.; *B* is .75 ma.; *C* is .4 ma.; *D* is 2.1 ma.; *E* is to be read by you and the reading recorded in Report Statement No. 12. This scale indicates the current in milliamperes which is passing through the meter. These scales are reproduced here for instruction purposes; the scale on your meter may not be exactly like these, but the same scale-reading methods will apply. Disregard the other three scales on your meter for the present; they will be taken up later.

the + meter terminal (marked *15*), travel through the other length of hook-up wire to the + *I* jack, then go through the red test lead to the + terminal of the flashlight cell.

Instructions for Report Statement No. 11. The report question which checks your work on this experiment is extremely important, because knowledge of the correct answer will enable you to trace electron flow in any d.c. circuit having a meter, even when there are no vacuum tubes present to indicate the direction of flow.

Using your actual observations and the discussion material as guides, *figure out the terminal at which electrons will enter your d.c. meter when it is connected in a d.c. circuit with correct polarity so as to give an up-scale deflection.* These answers are given in Report Statement No. 11 on the last page: *at the positive terminal; at the negative terminal; at both the positive and negative terminals.* Only one of these answers is correct; figure out which one it is, and make a check mark in the box following that answer.

EXPERIMENT 12

Purpose: **To demonstrate that the current which flows in a circuit will increase when the voltage is increased.**

Step 1. To learn how to read the lowest scale (marked I_M) *on your meter,* study the exact-size reproductions of this scale in Fig. *8.*. Observe that the scale reads from 0 to 3; these scale values represent milliamperes of current flowing through the meter, for your instrument is basically a milliammeter having a range of from 0 to 3 milliamperes.

When the maximum permissible current of 3 ma. is flowing through the meter, the pointer will be at *3* on scale I_M, as shown in Fig. *8A;* you would read this as 3 ma. When the pointer is on any other numbered line on this scale, the number below the line indicates the current in milliamperes.

When the pointer is on a short unnumbered line between two numbered lines, the meter reading is a value halfway between the values of the two adjacent numbered lines. Thus, you would read 1.5 ma. when the pointer is on the short line between *1* and *2*, and you would read 2.5 ma. when the pointer is on the short line between *2* and *3*.

Whenever the pointer is in between two lines on this scale, mentally divide the space between the two lines into equal smaller spaces and estimate the meter reading. For example, if the pointer is about halfway between lines marked *.5* and *1*, as in Fig. *8B*, you would estimate the meter reading to be .75 ma. If the pointer is as shown in Fig. *8C*, where it is closer to *.5* than to *0*, you might estimate the reading to be .4 ma. Finally, if the pointer is as shown in Fig. *8D*, you would estimate the reading to be about 2.1 ma. Values which you would estimate for other pointer positions are shown in Fig. *8F*.

Step 2. To secure 1.5, 3 and 4.5-volt d.c. voltage sources for this experiment, first take each cell in turn and tin the upper surface of its positive terminal strip for about one-fourth inch from the free end, then tin the under surface of its negative terminal in the same manner so as to secure surplus solder at these points.

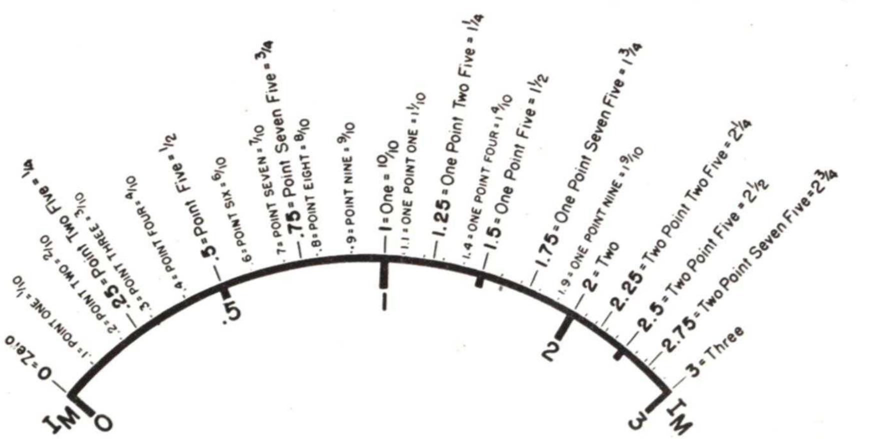


FIG. 8F. This enlarged view of the I_M scale of your meter can be used as a guide when questions arise in connection with meter readings. Various possible pointer positions are indicated by the thin lines above the scale. Estimated readings for typical positions are specified in three ways—first, as you would record the decimal value in a table; second, as a radio man would say it; third, in the form of common fractions.

Now arrange three of your previously prepared flashlight cells exactly in the manner shown in Fig. *9A*, so that the — terminal strip of one cell is over the + terminal strip of the adjacent cell. Bend the terminal strips so that they will touch each other when they are overlapping about ¼ inch in this manner, then apply the heated soldering iron tip in turn to each point where the strips overlap. Hold the soldering iron on each of these lap joints only long enough to melt and fuse together the solder in between the strips. Fig. *9B* shows the cells connected together.

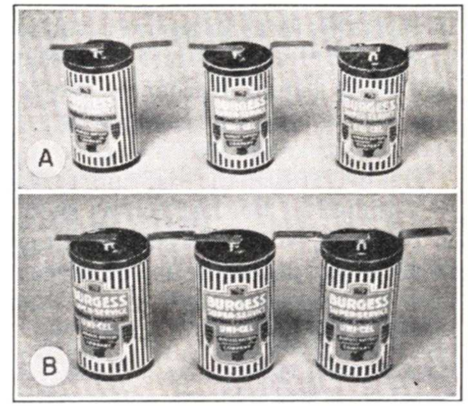


FIG. 9. Method of connecting three flashlight cells together in series aiding to permit obtaining three different values of d.c. voltage (1.5 volts, 3 volts and 4.5 volts).

Step 3. To secure practical experience in measuring the current in a circuit, attach the alligator clip of the black test lead to the — terminal at one end of your cell group. (The probes should be plugged into the panel jacks exactly as they were for Experiment 11, with red in +*I* jack and black in —*I*.) Now attach the red alligator clip to the + terminal of this same cell as shown in Fig. *10A*, so as to secure a voltage of 1.5 volts. Read on scale I_M of your meter the amount of current flowing, discon-

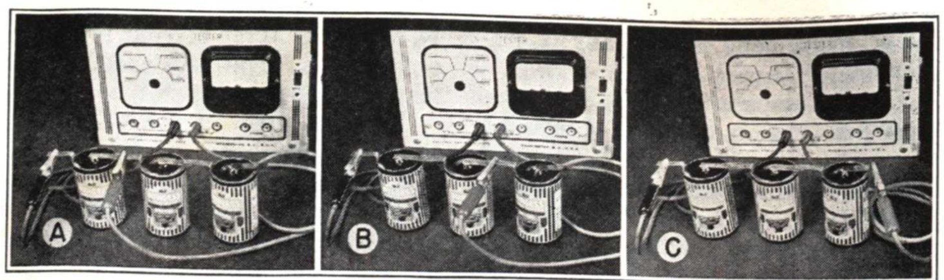


FIG. 10 These illustrations show you how to set up the three circuits in which you make current measurements as a part of Experiment 12. Note that the red probe is plugged into the +I jack, and the black probe is plugged into the −I jack. Leave the test probes in these jacks until you are told to remove them in Experiment 16.

nect the red clip, and record your reading in the first line of Table *12*.

Now attach the red clip to the + terminal of the middle cell as shown in Fig. *10B*, so as to secure a voltage of 3 volts. Read the meter on scale I_M just as before, disconnect the red clip, and record your result in the second line of Table *12*.

Finally, attach the red clip to the + terminal of the last cell as shown in Fig. *10C*, so as to secure a voltage of 4.5 volts. Read the meter, disconnect the red clip, and record your result in the last line of Table *12*.

CAUTION: Do not leave the meter connected to a flashlight cell or battery for more than a few minutes at a time; it is always better to disconnect one lead of the meter as soon as you take a reading, and leave it disconnected until you are ready for the next reading.

Look squarely at the meter when reading it, to secure consistently accurate readings; in other words, your eyes should be directly in front of the meter scale whenever you take a reading.

Discussion: The meter which is furnished you in Radio Kit 2RK-1 has four distinct scales. The only one which applies directly to the meter is the lowest scale, marked I_M, covering a range of from 0 to 3 ma. Ordinarily, this would be the only scale you would find on a meter of this type; the other three scales are provided for the NRI Tester in which you will use this meter after completing Experiment 20. For the present, therefore, it is entirely sufficient for you to know how to read only the lowest meter scale.

Do not worry too much about reading the meter accurately at this time. In the first place, accurate readings are seldom required in radio work. Furthermore, you will automatically acquire the ability to estimate meter readings as you secure experience with your meter. Just remember that a meter scale is like an ordinary ruler, and is read in much the same manner.

When you have a number of separate voltage sources and want to connect them together in such a way that the voltages add, you always connect them in the manner described in Step 2. This connection is known as *series aiding* (or simply as a *series connection*), for the voltage sources (flashlight cells) are connected in series in such a way that their voltages aid each other. Thus, if one cell gives 1.5 volts, two cells connected in series aiding will give 3 volts, and three cells will give 4.5 volts.

A comparison of the three meter readings which you obtained in Step 3 will show you that the current increases when you increase the source voltage from 1.5 volts to 4.5 volts. This experiment which you perform therefore proves the basic radio rule that the current in a circuit will increase when the voltage is increased. Conversely, it proves that the circuit current will decrease when the voltage is reduced.

Two factors determine the amount of current which will flow in a circuit; *the value of the source voltage, and the amount of opposition or resistance which the circuit offers to current flow*. In the three circuits which you set up in Step 3, the flashlight cells serve as d.c. voltage sources. As to resistance, we can say definitely that every electrical part has resistance. Sometimes this resistance is very large, so that electron flow is almost completely blocked, while in other

D.C. SOURCE VOLTAGE IN VOLTS	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CURRENT IN MA.
1.5	.75	.7	.75
3.0	1.6	1.6	1.50
4.5	2.25	2.3	2.25

TABLE 12. Record your results for Experiment 12 here

cases the resistance is so small that it can be neglected.

In the circuits of Step 3, each 1.5-volt dry cell has a resistance of about .5 ohm. The terminal strips, the test leads, the alligator clips, the jacks on the panel and the lengths of hook-up wire also have resistance, but in each case this resistance is lower than .5 ohm. The milliammeter has a resistance of about 2,000 ohms; this is so much higher than the resistance of the other parts in the circuit that we can call it the predominant resistance and neglect all other resistance. We thus have voltages of 1.5, 3 and 4.5 volts respectively, acting in a simple circuit having an effective total resistance of about 2,000 ohms.

Computing Circuit Current. Let us see what the value of circuit current will be when computed according to Ohm's Law for our first circuit, in which a d.c. voltage source of 1.5 volts is sending electrons through a circuit having a resistance of 2,000 ohms.

As you learned in your regular lessons, Ohm's Law says that the current in amperes is equal to the voltage in volts divided by the resistance in ohms. In our case, then, the current in amperes will be equal to 1.5 divided by 2,000, which is .00075 ampere. To convert this current value into milliamperes, we multiply by 1,000, and get .75 ma. as the computed value of circuit current. This computed value is listed in Table *12*, for convenience in comparing it with your own reading and with the reading of .7 ma. which we obtained in the NRI laboratory.

If the reading which you obtained is fairly close to the computed value (any reading between .5 ma. and 1.0 ma. can be considered as sufficiently close for all practical purposes in this particular experiment), you can consider that you have proved the validity of Ohm's Law in your d.c. circuit.

Whenever you double the source voltage value, as you did by adding another dry cell to your circuit, you would naturally expect that the current would double also. According to Ohm's Law, 3 volts acting on 2,000 ohms gives a current of 3 divided by 2,000, or .0015 ampere. This corresponds to 1.5 milliamperes, a computed value of circuit current which is exactly twice the value you computed for a 1.5-volt d.c. source. Likewise, your own current reading for 3 volts should be approximately twice the reading which you obtained for 1.5 volts.

With a d.c. source voltage of 4.5 volts, you would expect the computed current value to be three times that obtained with 1.5 volts. Dividing 4.5 by 2,000 gives .00225 ampere, which is equal to 2.25 ma. This is exactly three times the value computed for 1.5 volts, as you expected. Compare you own current reading for 4.5 volts with the computed value; if your reading is somewhere between 2 and 3 ma., you can consider your work on this experiment to be entirely successful, and you can consider that you have demonstrated how Ohm's Law holds true in a simple d.c. circuit.

Extra Information. You could safely apply as high as 6 volts directly to your meter without damaging it, since the full-scale value is 3 ma. (6÷2,000 =.003, or ma.). Your milliammeter can thus be used as a 0-6 volt d.c. voltmeter simply by multiplying the readings on scale I_M by 2. When using your meter in circuits having voltages higher than 6 volts, however, special precautions must be observed; these will be taken up later. In other words, never connect your meter alone directly to the terminals of a 22.5-volt or 45-volt B battery.

Some milliammeters have very much lower resistance than the meter which you used in Step 3. For this reason, never connect *an unknown milliammeter* across a dry cell *or any other voltage source* until you know exactly what the characteristics of the meter are. In some cases you may burn out the meter when doing this, for even the 1.5-volt value of a single dry cell may send through the meter a larger current than that for which it was designed.

Instructions for Report Statement No. 12. The question for this experiment is a test of your ability to read the meter on scale I_M with reasonable accuracy for practical radio work. After you have completed this experiment and studied the discussion, turn to the exact-size reproduction of this meter scale in Fig. *8E* and figure out what the meter reading would be when the pointer is at the position shown. Now turn to Report Statement No. 12 on the last page, and place a check mark in the box following the meter reading which you consider to be correct for Fig. *8E*.

EXPERIMENT 13

***Purpose:* To demonstrate that the current flowing in a circuit will be reduced when the resistance in the circuit is increased, and to prove for yourself the basic fact that the current is the same at all points in a series circuit.**

Step 1. To measure the current before and after you insert a 910-ohm resistance into a simple d.c. circuit, connect your meter across the group of three flashlight cells just as you did for the final measurement in Experiment 12, read the meter on scale I_M, disconnect the red clip, and record the current value on the first line in Table *13*.

As explained on page 2, parts 2-11, 2-13, and 2-14 now have the new post-war "standard" values of 6.8 megohms, .24-megohms, and 910 ohms, respectively. Use them in place of the 6.7-megohm, .24-megohm, and 900-ohm values shown in the following tables and diagrams. They will give essentially the same results for the experiments as the old values, and they will tend to improve the accuracy of the NRI Tester you are to build.

Now solder one lead of a 910-ohm resistor (Part *2-14*) to the + terminal at the end of the cell group, in the manner shown in Fig. *11*. To make this temporary soldered joint, simply tin the end of the resistor lead liberally with rosin-core solder, hold

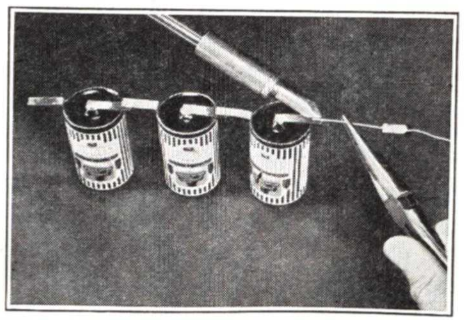


FIG. 11. To solder a resistor to a battery terminal strip by means of a lap joint, tin both the lead and the end of the strip, hold the resistor on the terminal strip with long-nose pliers as shown here, and apply the heated soldering iron.

this lead over the positive terminal strip with long-nose pliers, apply the heated soldering iron tip to the lead, then remove the iron and hold the resistor rigid until the solder hardens. Now attach the red clip to the other lead of this resistor while still leaving the black clip on the — terminal of the cell group, read the meter on scale I_M, disconnect the red clip, and record the result on the second line in Table *13*.

STEP	NATURE OF MEASUREMENT	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CIRCUIT CURRENT IN MA.
1	CURRENT THRU METER. (E = 4.5 V.)	2.25	2.3	2.25
	CURRENT THRU 900Ω AND METER (E = 4.5 V.)	1.55	1.6	1.55
2	CURRENT AT POINTS 8–9	1.55	1.6	1.55
	CURRENT AT POINTS 6–7	1.55	1.6	1.55
	CURRENT AT POINTS 4–5	1.55	1.6	1.55
	CURRENT AT POINTS 2–3	1.55	1.6	1.55

TABLE 13. Record your results for Experiment 13 here.

Step 2. To prove that the same current flows through all parts of a series circuit, measure the current at three different points in a circuit with your milliammeter, in the following manner:

Cut off an 11-inch length of push-back hook-up wire (Part *2-17*), push back the insulation for about ¾ inch from each end, then solder one end to negative cell terminal *1* in Fig. *12A* by means of a lap joint after first applying additional solder to the top surface of this terminal.

Now attach the red clip to resistor lead *8*, and attach the black clip to the other end of the hook-up wire (marked *9* in Fig. *12A*). Read the meter on scale I_M, disconnect both the red and black clips, and record the result in Table *13* as the current flowing at points *8-9* in your circuit.

Next, measure the current at points *6-7* by unsoldering resistor lead *7* from postive terminal *6*, then soldering end *9* of the hook-up wire to resistor lead *8* by means of a temporary hook joint as shown in Fig. *12B*. Attach the red clip to positive terminal *6*, and attach the black clip to resistor lead *7*. Read the meter on scale I_M, remove both clips, and

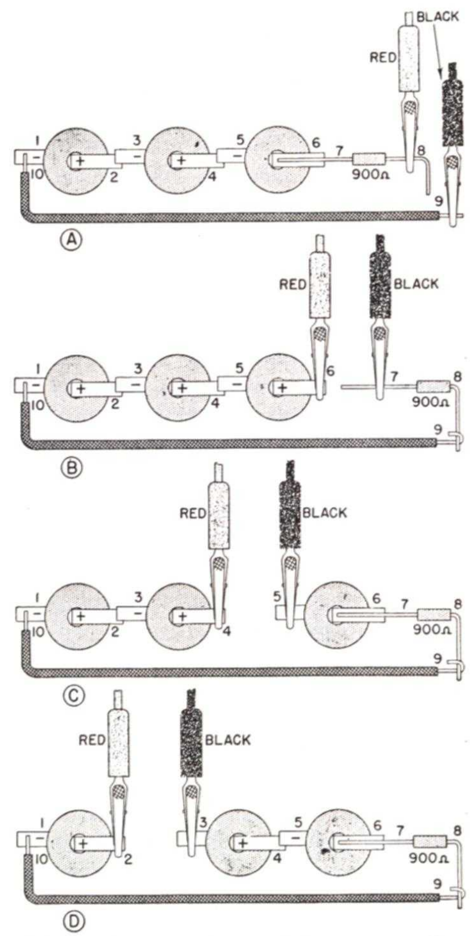


FIG. 12. Use these four milliammeter connections to prove for yourself that the same current value flows through all points in a series circuit.

record the result in Table *13* as the current flowing at points *6-7*.

Now separate terminal strips *4* and *5* by applying the heated soldering iron to the lap and moving the cells apart. Resolder resistor lead *7* to terminal *6*, as shown in Fig. *12C*. Attach the red clip to terminal *4*, and attach the black clip to terminal *5*. Read the meter on scale I_M, remove both clips, and record your result in Table *13* as the current flowing at points *4-5*.

Separate terminal *2* from terminal *3* by unsoldering. Resolder terminal *4* to terminal *5* as shown in Fig. *12D*. Place the red clip on terminal *2*, and replace the black clip on terminal *3*. Read the meter on scale I_M, remove both clips, and record your result in Table *13* as the current flowing at points *2-3*. Do not disconnect this set-up yet, because you will make one more measurement with it for Report Statement No. 13 after studying the discussion.

Discussion: For your first measurement in Step 1, the meter reading should be essentially the same as for the last measurement you made in Experiment 12, since the circuits are identical. When you increase the circuit resistance by inserting a 910-ohm resistor in the circuit, as you did for the second measurement in Step 1, you are increasing from 2,000 ohms to 2,910 ohms the opposition which the circuit offers to electron flow. According to Ohm's Law, the current will decrease when the circuit resistance is increased, hence the second reading which you record in Table *13* should be smaller than the first reading. If you do obtain this smaller reading, you know that you have performed the experiment correctly and have verified Ohm's Law again.

Computing Circuit Current. With a circuit resistance of 2,910 ohms and a voltage of 4.5 volts, Ohm's Law tells us that the circuit current in amperes will be 4.5 divided by 2,910, or .00155 ampere. This is equivalent to 1.55 ma. The second value which you recorded in Table *13* should correspond approximately to this computed value.

If you measure essentially the same meter readings at the four points where you measure current in Step 2, you have proved the fundamental radio principle that *the current is the same at all points in a series circuit.* Remember to tap the top of the meter lightly each time before you take a reading when the pointer is near zero, so as to offset bearing friction. Remember to look squarely at the meter from a position directly in front of it when taking a reading. If you read the meter from an angle, you will obtain a different value than if you were reading it properly.

In any series circuit, the voltage source "feels" the total resistance of the circuit, regardless of where or how this resistance is distributed throughout the circuit. As a result, only the correct current (correct electron flow) for the total circuit resistance can flow, and this current will be the same value at all points in the series circuit.

Instructions for Report Statement No. 13. In order to answer this report statement and prove that you have mastered the measuring techniques involved, connect three dry cells, the meter, a 910-ohm resistor and an 18,000-ohm resistor all in series and measure the current flowing in this circuit.

You can arrange these parts in any desired order as long as they are all in series; thus, you could have the meter connected to terminals *2* and *3* as shown in Fig. *12D*, and insert the 18,000-ohm resistor (Part *1-16*) between *1* and *10* after unsoldering the wire from terminal *1*. The total circuit resistance is now 2,000 + 910 + 18,000, which is 20,910 ohms.

Compare your measured current value in ma. for this circuit with the current obtained in Step 2 for a total circuit resistance of 2,910 ohms, then turn to the report statement on the last page and place a check mark in the box following the answer which describes your result.

EXPERIMENT 14

***Purpose:* To demonstrate that a milliammeter in series with a resistor can be used as a voltmeter.**

Step 1. To obtain a meter reading when a 4.5-volt d.c. source is connected in series with your meter and an 18,000-ohm resistor, take the 18,000-ohm resistor which was supplied you as Part *1-16* in Radio Kit IRK and solder one lead of it to the — terminal of your 3-cell battery in the manner shown in Fig. *13A*. Now attach the black clip to the other lead of this resistor, and attach the red clip to the + terminal of your group of cells. Read the meter on scale I_M, remove both clips, and record your result in Table *14* as the current in ma. flowing through this circuit when the source voltage *E* is 4.5 volts. The meter reading will be very low, less than .25 ma., but estimate its value roughly.

Step 2. To secure a meter reading when a 45-volt battery is connected in series with your meter and an 18,000-ohm resistor, unsolder the 18,000-ohm resistor from the flashlight cell group, bend a large hook in a clockwise direction at the end of one resistor lead with long-nose pliers, then attach this lead to the —B terminal of your 45-volt B battery, as shown in Fig. *13B*. This terminal is simply marked "—" on most B batteries, but from now on we will refer to it as the "—B" terminal (pronounced *minus bee*), just as radio men do. To make the connection to —B, loosen the knurled nut, hook the lead around the screw in a clockwise direction as shown in Fig. *14*, then tighten the nut.

Whenever you make a temporary connection to a terminal screw or part with a wire or lead, bend the

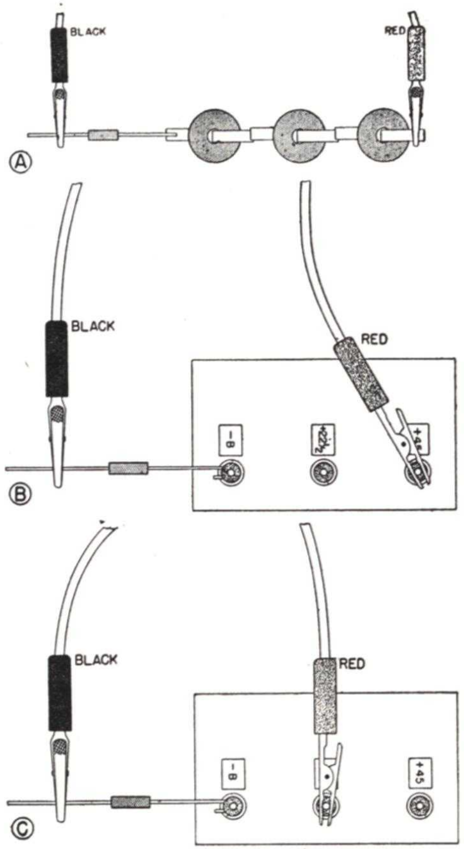


FIG. 13. The three circuits illustrated here all have the same total resistance (the meter with its resistance of 2,000 ohms is not shown, but is connected to the other ends of the two test leads in each case), but each circuit has a different voltage. In Experiment 14 you measure the current in each circuit and note its relationship to the circuit voltage, thereby demonstrating how a milliammeter can be used as a voltmeter.

hook in a clockwise direction as indicated in Fig. *14*, so that the hook will close rather than spread apart when you tighten the nut.

Now attach the black clip to the other resistor lead, and attach the red clip to the +45 terminal of your B battery. Read the meter on scale I_M, remove the red clip, and record your result in Table *14* as the current in ma. flowing through this circuit when the source voltage is 45 volts.

Step 3. To secure a meter reading when a 22.5-volt battery is connected in series with your meter and an 18,000-ohm resistor, place the red clip on the +22½ terminal of your B battery without disturbing the black clip or changing any other part of the circuit. This arrangement is shown in Fig. *13C*. Read the meter on scale I_M, remove both test clips, and record your result in Table *14* as the current in ma. flowing through this circuit when the source voltage E is 22.5 volts. Finally, disconnect the resistor from the battery.

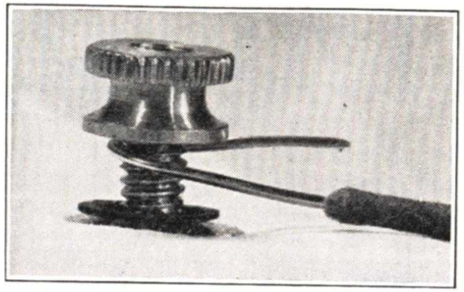


FIG. 14. Whenever you connect a wire or lead to a terminal screw, always bend the hook in a clockwise direction as shown here. This is the same direction in which you turn the nut when tightening it, and therefore the hook will tend to close rather than spread apart and come off when the nut is tightened. Lock washers are not necessary on battery terminals during experimental work, but when used, they help to prevent the terminal nut and wire from loosening.

CAUTION: Do not connect a 22.5 or 45-volt battery directly to the meter terminals (without the 18,000-ohm current-limiting resistor). Any voltage higher than 6 volts may damage the meter if applied directly.

Discussion: With an 18,000-ohm resistor in series with the 2,000-ohm resistance of your meter, the total circuit resistance becomes 20,000 ohms. This is ten times the resistance of the circuit using the meter alone. According to Ohm's Law, the circuit current should be reduced ten times (to 1/10 of its original value) when the circuit resistance is increased ten times. In Step 1 of Experiment 13 you obtained a current value somewhere near 2.25 ma. for a circuit including only the meter and a 4.5-volt battery, so you would naturally expect the meter reading in Step 1 of this experiment to be about 1/10 of this value, or about .2 ma.

Computing Circuit Current. According to Ohm's Law, the circuit current in amperes for the circuit used in Step 1 will be 4.5 divided by 20,000, which is .000225 ampere, or .225 ma.

In Step 2, you increased the battery voltage to 45 volts, while still keeping the circuit resistance at 20,000 ohms. If Ohm's Law holds true, this ten-times increase in voltage will make the current increase ten times. The current reading which you obtain for Step 2 should therefore be approximately ten times the reading you obtained for Step 1.

Computation. According to Ohm's Law, the current for Step 2 will be 45 divided by 20,000, which comes out to be 2.25 ma. This is exactly ten times the computed current value obtained for Step 1.

When you use a 22.5-volt d.c. source in Step 3, you are cutting the voltage to half the value employed in Step 2. If the current you measure is likewise cut approximately in half, you have again checked Ohm's Law.

Computation. According to Ohm's Law, the computed current for Step 3 is 22.5 divided by 20,000, which is 1.13 ma.

Now study your results in Table 14 for a few minutes. Note that the current increases in proportion to increases in the voltage, and the current decreases likewise in proportion to decreases in the voltage. Thus, there is a definite relationship between the meter reading and the voltage employed in the circuit. In fact, if you marked 4.5 volts on your meter scale at the pointer position obtained in Step 1, marked 45 volts at the pointer position obtained in Step 2, and marked 22.5 volts at the pointer position for Step 3, then filled in the missing voltage values on the scale by repeating the experiment for other known voltages, *you would use your meter with its 18,000-ohm resistor to read voltages directly.*

In other words, this experiment has shown definitely that *any milliammeter can be used to measure higher voltages than could safely be applied to the meter alone, provided a series resistor of the proper value* (such as the 18,000-ohm resistor employed in this case) *is used to extend the voltage range,* and the meter scale is recalibrated to read in volts instead of in milliamperes.

A current of 3 ma. through your meter will give you a full-scale deflection on scale I_M. Since the meter has a resistance of 2,000 ohms, Ohm's Law tells us that the voltage needed for a full-scale deflection will be .003 times 2,000, or 6 volts. In other words, if you connected your meter *alone* to a 6-volt battery, you would secure approximately a full-scale deflection on scale I_M.

To measure voltages up to 6 volts with your meter, connect the meter directly to the voltage source with the proper polarity, read the meter on scale I_M, and multiply the scale reading by 2 to get the actual voltage in volts. Thus, a scale reading of 2.25 would correspond to 4.5 volts.

By placing an 18,000-ohm resistor in series with your meter, you can increase the total circuit resistance ten times, and can safely apply ten times as much voltage to the meter circuit without exceeding the safe current of 3 ma. To prove this, we again resort to Ohm's Law.

STEP	NATURE OF MEASUREMENT	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CIRCUIT CURRENT IN MA.
1	CURRENT THRU 18,000Ω AND METER. (E = 4.5 V.)	.2	.2	.225
2	CURRENT THRU 18,000Ω AND METER. (E = 45 V.)	2.5	2.1	2.25
3	CURRENT THRU 18,000Ω AND METER. (E = 22.5 V.)	1.25	1.0	1.13

TABLE 14. Record your results for Experiment 14 here.

Computation. Let us say that we have the maximum safe meter current of 3 ma. flowing through the circuit resistance of 18,000 ohms + 2,000 ohms. According to Ohms' Law, the voltage required to send .003 ampere (3 ma.) through a total resistance of 20,000 ohms is .003 × 20,000, or 60 volts. Thus, the insertion of an 18,000-ohm resistor in series with your meter allows you to apply voltages up to 60 volts to your measuring circuit without making the meter read higher than *3* on scale I_M.

To measure d.c. voltages up to 60 volts, connect your meter in series with an 18,000-ohm resistor to the terminals of the voltage source (being sure to get the correct polarity), read the meter on scale I_M, and multiply the scale reading by 20 to get the actual voltage in volts.

When a resistor is placed in series with a meter in this manner to increase the voltage range, the resistor is known as a *voltage multiplier.*

To make your meter read up to 600 volts, which is 100 times the voltage which gives full-scale deflection of the meter alone, the meter and voltage multiplier together must have a resistance of 100 times 2,000 ohms, or 200,000 ohms. Since the meter alone has a resistance of 2,000 ohms, the voltage multiplier should have a value of 198,000 ohms. With this 198,000-ohm series resistor or voltage multiplier, you could then read voltages directly up to 600 volts on your meter simply by multiplying the reading on scale I_M by 200.

Multiplier Circuit Arrangement. By providing a number of different series resistors of the proper values, along with a switch which permits inserting any one of them in series with the meter, a milliammeter like yours can be made to serve for a number of different voltage ranges. Many of the meters used in radio work, particularly in professional multimeters, are arranged in this manner.

Ohms-Per-Volt Rating. With the meter resistance of 2,000 ohms used alone, the maximum voltage range is 6 volts; with a series resistor being used to increase the meter circuit resistance to 20,000 ohms, the maximum voltage range is 60 volts; with a total meter circuit resistance of 200,000 ohms, the maximum voltage range is 600 volts. When we divide the meter circuit resistance by the maximum voltage range in any one of these cases, we get 333 ohms. This value is known as the *ohms-per-volt rating* of your meter, and is an indication of its sensitivity when used as a voltmeter.

A common sensitivity rating for meters used in radio work is 1,000 ohms-per-volt. Some voltmeters have sensitivities of 5,000 ohms-per-volt, while a few even go as high as 20,000 ohms-per-volt. The vacuum tube voltmeter which you will build after completing this group of ten experiments has a full-scale sensitivity of over 2,000,000 ohms-per-volt on one range, and all of the other ranges are higher than 20,000 ohms-per-volt. This means that your instrument will be comparable with the best individual meters employed in radio work.

Voltage Multiplier Rule.* *To find the correct value for a voltage multiplier resistor which is to give a desired voltage range, multiply the ohms-per-volt rating of the meter by the maximum voltage range desired, then subtract from the resulting value the resistance of the meter itself.

Instructions for Report Statement No. 14. The question for this experiment checks your mastery of the discussion, so do not try to answer Report Statement No. 14 until you understand fully every single sentence in the discussion. You should realize that any d.c. milliammeter can be used as a d.c. voltmeter, and should have a general understanding of how voltage multiplier resistors can be used to increase the voltage range.

Here is the test problem: Suppose you are using your meter as a 0-60 volt d.c. voltmeter (by placing an 18,000-ohm voltage multiplier resistor in series with the meter) to measure an unknown d.c. voltage. You connect the meter and multiplier to the terminals of the voltage source with proper polarity and get a reading of 2 on scale I_M. What is the actual voltage of this source? Figure it out, referring to the discussion again if necessary, then place a check mark after the value which you consider to be correct in Report Statement No. 14 on the last page.

EXPERIMENT 15

***Purpose:* To demonstrate the use of shunt resistors for increasing the current range of a milliammeter.**

Step 1. To secure experience in using your milliammeter with a 100-ohm shunt resistor for measuring higher current values, take a 100-ohm resistor (Part *2-15)* and connect it to the meter terminal lugs with temporary soldered joints as shown in Fig. *15A.*

Take a 910-ohm resistor (Part *2-14*) and connect one of its leads to the —B terminal of your B battery, as shown in Fig. *15B.* With the test leads still in the *I* jacks exactly as shown in Fig. *7,* attach the black clip to the other lead of the 910-ohm resistor.

Now complete the circuit by attaching the red clip to the +45 battery terminal. Read the meter on scale I_M, remove the red clip immediately from the +45 terminal, then record your reading in Table *15.* Do not leave the red clip connected to the +45 terminal any longer than is necessary to secure the reading, for otherwise you will exhaust the B battery.

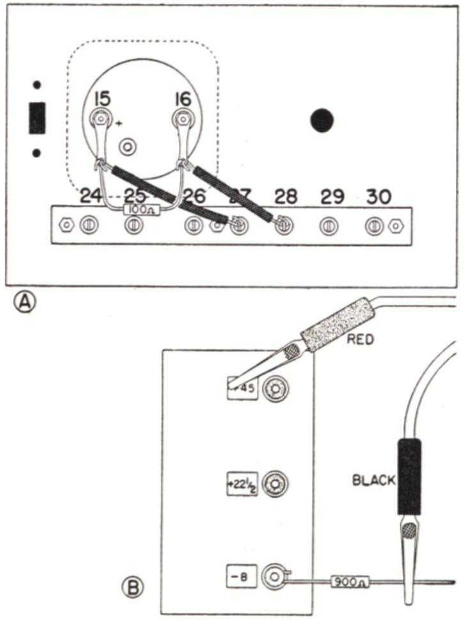


FIG. 15. By placing a 100-ohm shunt resistor across your meter in the manner shown at *A* here, you are able to measure (Experiment 15) the current in the circuit shown at *B*, even though this current is considerably higher than the 3-ma. maximum value which can be passed through the meter alone.

STEP	NATURE OF MEASUREMENT	YOUR METER READING ON SCALE I_M	N.R.I. METER READING ON SCALE I_M	COMPUTED METER CURRENT IN MA.
1	CURRENT THRU 900Ω AND METER SHUNTED BY 100Ω (E = 45 V.)	2,5	2.2	2.14

TABLE 15. Record your results for Experiment 15 here.

Discussion: In a circuit consisting of a 45-volt battery and a total resistance of 910 + 100 ohms, the current would be 45 ma. (45 divided by 1,010 = .045 ampere, or 45 ma.). This current cannot be measured directly with your meter, since the maximum current the meter can safely pass is 3 ma. In this experiment, we use a shunt resistor (100 ohms) to increase the range of the milliammeter enough to permit measurement of this high current.

In the circuit of Fig. *15,* the 100-ohm resistor is connected directly across the meter terminals. Let us see how this shunt resistor (usually called a *shunt*) limits the meter current to a safe value.

First of all, when a 2,000-ohm meter is connected across a 100-ohm resistor, the original total circuit resistance of 1,010 ohms (910 + 100) will be changed slightly. With 2,000 ohms in parallel with 100 ohms, the combined resistance is 95 ohms; 910 + 95 gives a total circuit resistance of 1,005 ohms. The change is so small, however, that for all practical purposes we can consider this total resistance to be still 1,010 ohms, and the circuit current still 45 ma. through the battery and the 910-ohm resistor.

When the 45-ma. circuit current reaches the parallel combination of the 100-ohm resistor and the meter, the current divides between these two parts. Naturally, most of the current goes through the 100-ohm resistor since it offers much lower opposition than does the 2,000-ohm resistance of the meter. Let us see exactly how the current divides.

Computation. Imagine that the 100-ohm resistor is replaced with twenty separate 2,000-ohm resistors connected in parallel. The combined resistance of this group of twenty resistors will be 100 ohms. (When resistors of equal value are connected in parallel, their combined resistance is equal to *the resistance of any one of them divided by the number of resistors* which are in parallel.)

When the meter is added in parallel with these twenty imaginary 2,000-ohm resistors, we will have twenty-one identical 2,000-ohm paths for current between the meter terminals. Each resistor will carry an equal amount of current, and the value of this current will be 1/21 of the total circuit current of 45 ma. In other words, the current through the 2,000-ohm meter (and through each imaginary 2,000-ohm resistor) will be 45 ma. divided by 21, or about 2.14 ma. Compare this computed value of meter current with the value you obtained and with the value of 2.2 ma. which we obtained in the NRI laboratory.

Since the meter gets only 1/21 of the total current, multiplying the meter reading on scale I_M by 21 will give us the actual circuit current when the meter is used with a 100-ohm shunt resistor. Multiplying the maximum meter reading of 3 ma. by 21 gives 63 ma. as the new full-scale range of the milliammeter when used with a 100-ohm shunt.

The number by which we multiply the meter reading is called the *multiplying factor* or scale conversion number.

When using the meter with a 100-ohm shunt as a 0-63 ma. d.c. milliammeter, read the meter on scale I_M and multiply the scale reading by 21 to get the actual current value in ma.

Practical Extra Information on Meter Shunts. When the current range of a meter is to be increased a definite number of times, place across the meter terminals a shunt resistor having a resistance equal to *the meter resistance divided by "one less than the multiplication factor desired."* For example, if you wished to increase the range of your 2,000-ohm milliammeter to 30 ma., which is an increase of ten times, you would use a shunt resistor equal to 2,000 divided by 9, or 222 ohms.

If we know the current value flowing in a circuit, we can find the multiplying factor for a meter-shunt combination by dividing the known current value by the meter reading for that current. For example, with a known current of 45 ma. and a meter reading of 2.2 (the NRI value obtained in this experiment), we would divide 45 by 2.2 and get 20.45 as the multiplying factor. When we consider the normal tolerances of the meter, resistors and batteries, this is very close to the computed correct value of 21. Even if we called it 20, as a practical radio man would probably do, the results would still be more than accurate enough for ordinary radio purposes.

When the resistance of a meter is not known and cannot conveniently be measured, the radio engineer prefers to use a somewhat different method for determining the required value for a shunt resistor. First of all, he determines the voltage required across the meter to give a full-scale deflection. This same voltage will act upon the shunt which is to be connected in parallel with the meter. He knows that the meter and shunt together must pass the new full-scale value of current, while the meter alone will pass its normal full-scale current value. Subtracting the meter current from the new full-scale value gives

the current flowing through the shunt resistor at a full-scale deflection. The engineer then uses Ohm's Law, and divides the shunt resistor voltage by the shunt resistor current; this gives him the required value of shunt resistance.

Here is an example: The range of a 1-ma. milliammeter is to be increased to 10 ma. by means of a shunt resistor. The engineer knows (or determines experimentally) that a voltage of .05 volt will send the normal full-scale value of current through the meter. This value of .05 volt is then the shunt voltage. The current flowing through the shunt at the new full-scale current value will be .010 ampere minus .001 ampere, or .009 ampere. The shunt resistance value will therefore be .05 divided by .009, which is 5.55 ohms.

Instructions for Report Statement No. 15. In order to supply the correct answer for this report statement, place the red clip on the +22½ terminal of the B battery while leaving everything else the same as for Step 1. Hold the clip on the +22½ terminal only long enough to read the meter on scale I_M. You will then be using your meter with its 100-ohm shunt as a 0-63 ma. milliammeter, and will be measuring the current flowing in a series circuit consisting of a 22.5-volt battery and a 910-ohm resistor. Record your meter reading on scale I_M in the first space in Report Statement No. 15 on the last page. Next, multiply your meter reading by 21 to get the actual current, and record this value in the second space in Report Statement No. 15.

EXPERIMENT 16

Purpose: **To demonstrate that a milliammeter can be used to measure resistance.**

Step 1. To connect your meter into a series ohmmeter circuit like that shown in the circuit diagram of Fig. 16, and to secure experience in measuring resistance values with this series ohmmeter, first remove the red and black test leads from the *I* jacks on the panel. Now remove the 100-ohm shunt resistor from the meter terminals, and disconnect the hook joint on jack *28* at the back of the panel without disturbing the other end of this lead. Place a small piece of cardboard (about 3 inches by 6 inches in size) on top of the chassis for insulating purposes, then place the group of three flashlight cells on this cardboard in the manner shown in Fig. *17A*, with the — terminal of

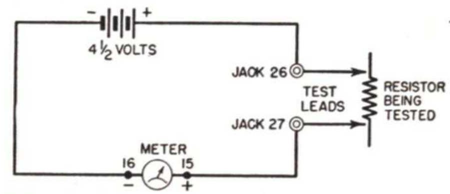


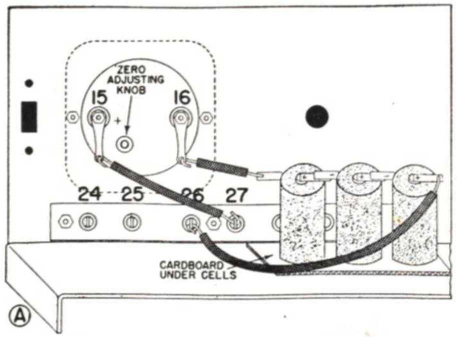
FIG. 16. Schematic circuit diagram for a series ohmmeter.

cell group near meter terminal *16*. Now solder the lead from terminal *16* to this — cell terminal by means of a lap joint.

With about a 9-inch length of hookup wire, connect the + terminal of the cell group to jack *26*, as shown in Fig. *17A*, making a lap joint at the cell and a hook joint at the jack.

Plug the test leads into the two *R* jacks on the front of the panel, as shown in Fig. *17B*. (The colors of the leads may be disregarded when making measurements of resistor values.) Your series ohmmeter is now ready for use.

Connect an 18,000-ohm resistor (Part *1-16)* to your ohmmeter by placing one test lead clip on each lead



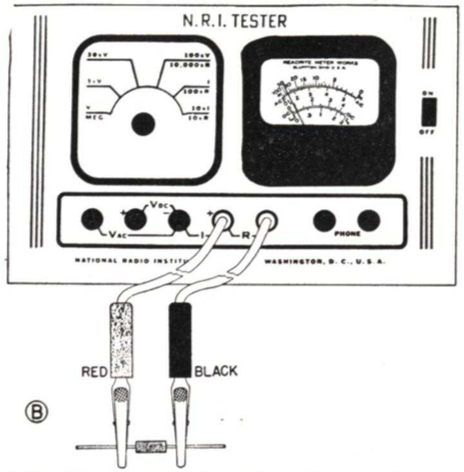


FIG. 17A (above). Rear view of panel, showing connections for the series ohmmeter which you set up in Step 1 of Experiment 16.

FIG. 17B (below). Method of connecting a resistor to the series ohmmeter.

of the resistor, as shown in Fig. *17B*. Read the meter on scale I_M, record your result on the first line in Table *16*, then disconnect the 18,000-ohm resistor completely.

Connect a 910-ohm resistor (Part *2-14*) to your ohmmeter by placing one clip on each resistor lead. Read the meter on scale I_M, record your result in Table *16*, and disconnect the resistor.

Connect a 100-ohm resistor (Part *2-15*) to your ohmmeter by placing one clip on each resistor lead. Read the meter on scale I_M, record your result in Table *16*, and disconnect the resistor.

Finally, try your ohmmeter with essentially zero resistance, by attaching one test lead clip to the other clip. Read the meter on scale I_M, record your result in Table *16* (on the zero-resistance line), then separate the test clips.

Important: Before beginning Step 2, read the report statement instructions at the end of this experiment and make the additional series ohmmeter measurement which is required.

Step 2. To connect your meter into a shunt ohmmeter circuit like that shown in the circuit diagram of Fig. 18A, and to secure experience in measuring resistance with a shunt ohmmeter, connect your parts in the manner shown in Fig. *18B*, in the following order:

Unsolder the group of three cells used in the previous step.

Unsolder the joint at jack *26*, then connect one end of the unsoldered lead to meter terminal *15* by means of a temporary soldered hook joint. To do this, apply the heated soldering iron to this soldering lug to melt the solder, then hook the wire into the hole in this lug alongside the wire already there. Or, if you prefer, simply make a lap joint on the lug.

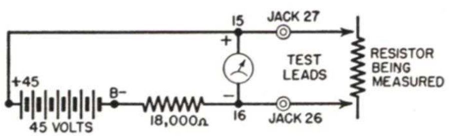


FIG. 18A. Schematic circuit diagram for a shunt ohmmeter.

Solder to jack *26* the free end of the lead which is still on meter terminal *16*.

Solder a 5-inch length of hook-up wire to one lead of the 18,000-ohm resistor (Part *1-16*) by means of a temporary hook joint. Connect the other end of this wire to the lug on

meter terminal *16* with a temporary soldered hook or lap joint.

Bend a large hook in the other end of the resistor lead, and connect this lead to the —B terminal of your B battery.

Turn the chassis around, and connect the alligator clips to the leads of the 910-ohm resistor (Part *2-14*) while leaving the probes in the *R* jacks. Last of all, take the 9-inch lead on meter terminal *15* and connect its free end to the +45 terminal of your battery. Read the meter on scale I_M, disconnect the lead from the +45 terminal *immediately* to conserve battery life, and record your result in the fifth line of Table *16*.

Connect a 100-ohm resistor (Part *2-15*) to this shunt ohmmeter in place

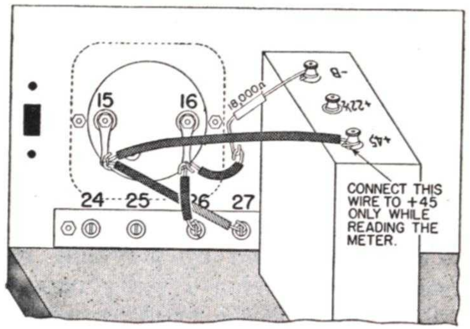


FIG. 18B. Rear view of panel, showing connections for the shunt ohmmeter which you set up in Step 2 of Experiment 16.

of the 910-ohm resistor, reconnect the lead to the +45 terminal, read the meter on scale I_M, disconnect the lead from the +45 terminal, and record your result in Table *16*.

Finally, place essentially zero resistance across your shunt ohmmeter by connecting one clip to the other, reconnect the lead to +45, read the meter on scale I_M, disconnect the lead from +45, separate the clips, and record your result on the last line in Table *16*. Disconnect the set-up completely now by unsoldering and re-

STEP	RESISTANCE BEING MEASURED IN OHMS	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.	COMPUTED CIRCUIT CURRENT IN MA.
1	18,000	2	.2	.225
	900	1.5	1.5	1.55
	100	2.5	2.2	2.14
	0	2.4	2.3	2.25
2	900	.9	.7	.74
	100	.1	.1	.12
	0	0	0	0

TABLE 16. Record your results for Experiment 16 here.

moving the resistor and the four lengths of hook-up wire, but *do not* remove the meter, its soldering lugs, or the jack strip. Separate the flashlight cells.

Important: Be sure to save all pieces of hook-up wire, no matter how small, for they can be used over and over again in later experiments.

Discussion: When using the group of three dry cells as the voltage source for a series ohmmeter in Step 1, the wiring is simplest if you place the cells on the chassis as shown in Fig. *17A*. However, when you are doing this be sure to use the piece of cardboard under the cells, to prevent the exposed cell bottoms from shorting through the chassis and draining the cells.

A *series-type* ohmmeter is basically an instrument in which the resistor being measured is connected in series with a milliammeter and a d.c. voltage source. The two test leads, which are plugged into the *R* jacks, serve as the terminals of your series-type ohmmeter. When these terminals are separated, corresponding to an infinitely high resistance value, no current flows through the meter and consequently it reads zero. When a resistor is connected to the ohmmeter terminals, the current flow as indicated by the meter will depend upon the voltage being used and upon the total circuit resistance (the meter resistance plus the value of the resistance being measured.)

Circuit Current Computation. By means of Ohm's Law, we can compute the current very easily in the ohmmeter circuit when an 18,000-ohm resistor is being measured (Step 1). Since the meter has a resistance of 2,000 ohms, the total circuit resistance in this case is 20,000 ohms. Dividing the circuit voltage of 4.5 volts by 20,000 ohms gives a current of .000225 ampere, or .225 ma.

With a 910-ohm resistor, the computed current becomes 1.55 ma., while for a 100-ohm resistor the computed current is 2.14 ma. With zero resistance across the ohmmeter leads in Step 1, the computed circuit current is limited only by the meter resistance, and is therefore 2.25 ma., just as was calculated for the same condition in Experiment 12. You can thus see that as we decrease the ohmic value of the resistor in a series-type ohmmeter circuit, the meter current goes up. Conversely, *increasing* the resistance makes the meter current go down.

By using additional resistors of known values, or by computation, we can determine what the meter reading on scale I_M would be for any resistor value. A scale giving values in ohms rather than in milliamperes could then be marked on the meter, so that resistance could be measured directly whenever a 4.5-volt battery was used in series with the meter. This is the basic principle of the widely used series-type ohmmeter.

In an actual commercial series-type ohmmeter, the voltage employed is sufficient to give slightly higher than a full-scale meter reading, and a variable resistor is placed in series with the meter or shunted across the meter. This resistor can be adjusted to make the meter read exactly full-scale when the ohmmeter leads are clipped together. This scheme therefore permits compensation for the natural reduction in battery voltage with age. The variable resistor which is used with the meter for this purpose is sometimes called the *zero ohmmeter adjustment.*

Theoretically, every ohmmeter scale should cover all resistance values from zero to infinity. Actually, however, the most useful range of an ohmmeter is that near the middle of its calibrated scale. Resistance values are always indicated on the remaining portions of the scale, but readings in these portions cannot be estimated with reasonable accuracy. For this reason, it is often advisable to provide several different resistance ranges for use with one meter.

The useful range of an ohmmeter can be increased by providing means for employing either higher or lower d.c. voltages, and by providing for each voltage value a series resistor which will limit the circuit current to the full-scale meter value when the ohmmeter terminals are shorted.

In Step 2, you deal with the basic principle of what is called a *shunt-type ohmmeter*. In this circuit, the meter and the 18,000-ohm resistor are connected in series with the 45-volt d.c. source at all times, and the terminal leads for the ohmmeter go to the meter terminals. When the clips are disconnected, the circuit current is somewhere near the computed value of 2.25 ma. (This was calculated in connection with Step 2 of Experiment 14.)

When your shunt-type ohmmeter is connected to a 910-ohm resistor, the

computed value of circuit current is .74 ma. The resistor provides an alternative path around the meter for current, and consequently we secure a lower meter reading than for the condition where no resistor is connected to the ohmmeter. With a 100-ohm resistor, the shunt path across the meter has even lower opposition to current flow, and consequently the meter reading drops still lower, to a value somewhere near the computed value of .12 ma. (Computations are not given since they are essentially the same as previous computations.)

Finally, when the ohmmeter clips are connected together to correspond to a zero-resistance condition, the meter is completely shorted and the reading drops to zero.

Thus, with a shunt-type ohmmeter the meter reading decreases as the value of the resistance being measured decreases. This is just exactly the opposite of the action observed for a series-type ohmmeter. Again, the meter could be calibrated and its scale marked to indicate directly the values of resistors being measured.

In commercial shunt-type ohmmeters, the scales are marked directly in ohms. Furthermore, the voltage source employed is high enough to give higher than full-scale deflection, and a variable resistance is inserted in series with the battery to permit compensation for natural aging of the battery.

As a general rule, series-type ohmmeters are employed for measuring high resistance values, and shunt-type ohmmeters are employed for measuring low resistance values. You can readily identify these types, for on a shunt-type ohmmeter the zero of the scale is always at the left, while with a series-type ohmmeter it is at the right.

Extra Information. When a series-type ohmmeter is properly adjusted, the insertion of a series resistor equal to the initial resistance of the circuit will cut the meter current in half, and consequently the meter pointer will take a mid-scale position.

When a shunt-type ohmmeter is properly adjusted, shunting the meter with a resistor equal in value to the meter resistance will cut the meter current in half, and the meter pointer will take a mid-scale position (assuming the meter resistance is negligibly low in comparison with the resistance value employed in series with the meter and battery).

To find the resistance of a d.c. milliammeter, connect the meter, a high-value variable resistance (about 50,000 ohms) and a voltage source all in series, choosing a voltage value which will give a full-scale meter reading when the variable resistance is adjusted. Now take another variable resistance of about the same value, shunt it *across* the meter, and adjust this second variable resistance until the meter reads exactly half of its full-scale current value. The ohmic value of the shunt variable resistance will now be exactly equal to the resistance of the meter, and can be measured with a conventional ohmmeter. This procedure is especially valuable when the resistance of a meter is so low that an ohmmeter battery would send an excessively large current through it during an ordinary resistance measurement.

Instructions for Report Statement No. 16. In order to supply the answer to this report statement, you must make one additional measurement with the series ohmmeter set-up described in Step 1 and shown in Fig. 16. Secure a meter reading for a parallel combination of 910-ohm and

100-ohm resistors by placing one lead of each resistor in the jaws of the red clip, and placing the other resistor leads in the black clip. Read the meter on scale I_M, compare your reading with those you obtained in Step 1, then turn to the last page and make a check mark after the answer in Report Statement No. 16 which describes your result. Now carry out Step 2 of this experiment.

Instructions for Mounting Batteries on Chassis

Step 1. To prepare for assembly of individual batteries in a compact group on the chassis, place before you the following batteries and parts:

One 1 1/2-volt A battery.
Eveready 742 with plug-in adapter, Burgess 4FH, or equivalent.

One 45-volt B battery.
Eveready 762-S, Burgess 5308, or equal.

Two 4 1/2-volt C batteries.
Eveready 761-T, Burgess 2370, or equivalent with four screw terminals, marked +, —1½, —3 and —4½.

One Battery Terminal Card.
This card is furnished with C batteries purchased from NRI. If you get your batteries elsewhere, you can make your own card according to later instructions.

One length of black lace (Part 2-20).
Corrugated cardboard (from battery shipping carton or any other box).
About 3 1/2 feet of ¾-inch wide friction tape (not furnished or absolutely needed, but will keep the batteries from sliding. You can buy a small roll from any hardware or dime store).
Assembled chassis and panel, with meter and jack strip mounted on panel.
One 2-inch length of hook-up wire.

The detailed battery instructions which start with Step 3 apply specifically to Eveready batteries. For those who use other makes of batteries, special instructions are given at the end of each step whenever necessary. In general, however, the battery assembly procedure is practically the same for all makes of equivalent batteries.

You will find that the instructions specify placing strips of black friction tape between the batteries. This is an optional procedure which you do not have to do unless you desire. The friction tape prevents the batteries from sliding out of position when you turn the chassis over to change connections underneath.

Note: If for any reason you are using batteries having different shapes or dimensions than the specified Eveready or Burgess units, you may change the arrangement of the batteries on the chassis or change the wire lengths, provided that you make the same electrical connections to the battery terminals as are specified in this manual.

Experiment with different positions until you secure an arrangement which gives a compact group fitting within the battery tabs on the chassis, with all battery terminals at the top or facing the front panel so the terminals will be accessible and battery connecting leads will be as short as is practical. If at all possible, arrange the two C batteries exactly as in Figs. 19B *and* 19C.

Step 2. Identify on top of the chassis with metal marking crayon the six holes which you previously marked *a, b, c, d, e* and *f* under the chassis. Do this carefully, one hole at a time, to make sure that each hole is marked the same above the chassis as it is below. These letters on top of the chassis should face the front panel, and should be in the positions shown in Fig. *21B*. If it is difficult for you to make neat letters while the panel is attached, you can temporarily remove the front panel. Be sure to replace the panel after you finish the lettering.

Step 3. Place one of the Eveready C batteries (761-T) in front of you, in exactly the position shown in Fig. *19A*, so that the terminals have *exactly* the positions shown in the diagram. Cut two strips of friction tape, each 2½ inches long,, and place these on the uppermost side of the battery

in the manner shown for strips *U* and *V* in Fig. *19A*. Now place the other C battery on top of this, in such a way that its + terminal is next to the —4½ terminal of the first C battery. Set the two batteries upright now in the position shown in Fig. *19B*.

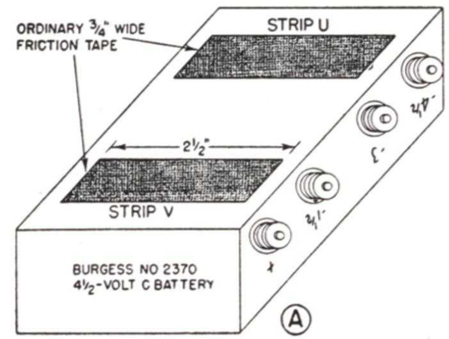
Note: For other makes of batteries, bear in mind that the strips of friction tape should be as long as possible without projecting beyond the batteries.

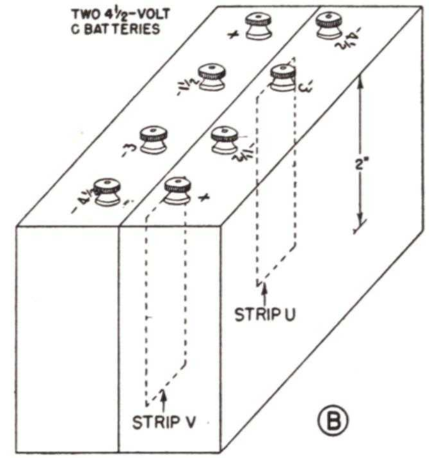
Step 4. Cut three pieces of corrugated cardboard from the packing carton in which the batteries were shipped. Make one piece 4 inches long and 2½ inches wide, and mark it with the letter *X*. Make the other two pieces each 4 inches long and 2¾ inches wide, and mark them *Y*. These will be used as packing around the 1½-volt A battery, so that four batteries can later be assembled into a uniform pack as shown in Fig. *19C*.

Note: For other battery makes, cardboard spacers may not be needed, or may have to be of different sizes. Bear in mind that spacers are used only to give a neat appearance to the battery group.

Step 5. Take the type 1024 plug-in adapter and push it into the holes found in the end of the Eveready 742 1½-volt A battery. The two adapter prongs are of different size, so there is only one position in which the adapter will fit. Now turn the battery so the + terminal of the adapter is at your *left,* and place the marking +1½A on the battery directly above the + terminal, as shown in Fig. *19C*. Next, place the marking —A on the battery directly above the — terminal. You can use your metal-marking crayon for these markings if you keep its point sharp.

Note: Some makes of A batteries will have standard terminal nuts and screws rather than a plug-in connecting system. On these, just mark the — terminal as —A, and mark the + terminal +1½A so as to conform to the marking in Figs. 19C *and* 19D.

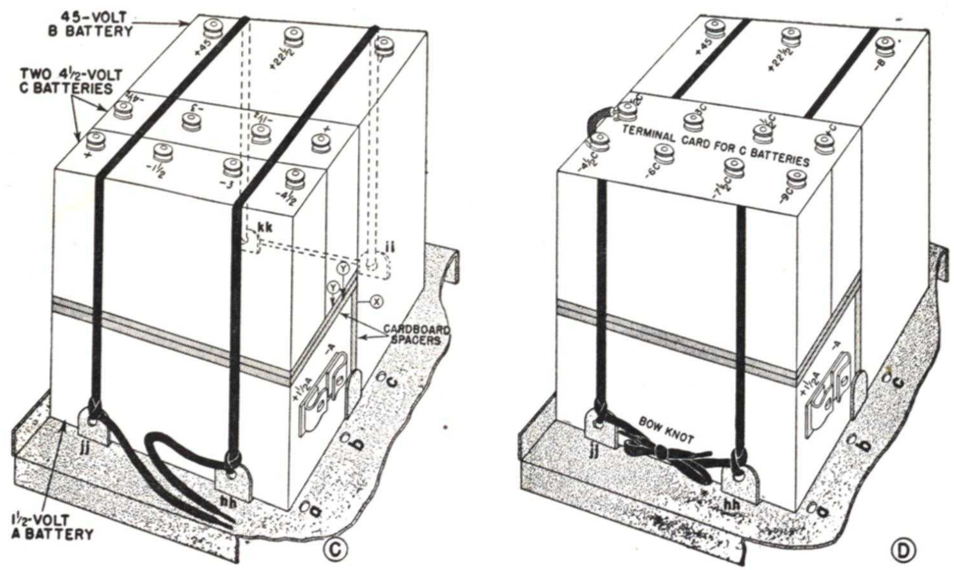




FIGS. 19A and 19B. Assembly of C batteries. The strips of friction tape are not absolutely essential but prevent the batteries from sliding out of position.

Step 6. Set your metal chassis in front of you with the panel facing you, so that battery tabs *hh* and *jj* on the chassis are at your left as in Fig. *19C*. Lay the 1½-volt A battery on the chassis, against these tabs, exactly as in the diagram.

Now cut six pieces of friction tape, each 3 inches long. Place one piece lengthwise on top of the A battery, and place another piece of tape lengthwise on the right side of the A battery. These pieces of tape will



Figs. 19C and 19D. Method of arranging the specified Eveready batteries on the chassis.

prevent the cardboard spacers from sliding out of position.

Place the smaller cardboard spacer (marked *X*) against the right side of the A battery, and place a 3-inch length of tape lengthwise on the right side of this spacer.

Now set the B battery on the chassis in an upright position, with the — terminal nearer the front panel, as in Fig. *19C*.

Place one of the larger cardboard spacers (marked *Y*) on top of the A battery, place a 3-inch length of tape lengthwise on this spacer, then place the remaining spacer *Y* on top. Now place the two remaining lengths of tape on top of the last cardboard spacer, arranging them lengthwise about ½ inch apart so that one strip will be under each of the C batteries which you now place in position exactly as shown in Fig. *19C*.

Step 7. Take the 45-inch length of black lace (Part *2-20*) and tie one end to battery tab *hh* with a simple knot, as shown in Fig. *19C*, leaving about 4 inches of lace projecting beyond the tab so you can tie a bow knot with it later. When pulled tight, this simple knot will hold adequately for your purpose.

Now run the lace across the tops of the batteries, and thread it through battery tab hole *ii* from the *inside* (lift up the B battery temporarily to do this). Bring the lace over to tab *kk* now and thread it through the hole from the *outside*. From *kk*, run the lace back over the tops of the batteries to tab *jj*, and thread it through the hole in this tab. Go over the entire length of lace to pull it tight with your fingers and make the lace lie flat, then tie a simple knot at tab *jj* just as shown in Fig. *19C*.

To prevent the lace from slipping while tying the knot, you can place the blade or shank of a medium-size screwdriver between the tab and the battery block, as shown in Fig. *19E*. Finally, tie a bow knot with the loose ends, as shown in Fig. *19D*.

Note: The 45-inch lace should be long enough to go twice across any combination of other makes of batteries, but in some cases it may not be necessary to tie the bow knot. With smaller batteries, it may be possible to run the lace three times across the group, from hh to ii to jj to kk. Any lacing arrangement which keeps the batteries securely on the chassis is satisfactory.

Step 8. Remove the nuts from all eight C battery terminals. If there are lock washers on the terminals, remove these also and set them aside. You do not have to use lock washers on battery terminals during your experimental work.

Take the battery terminal card furnished with your NRI batteries, and cut out each of the eight rectangles with a sharp pen knife. Now push the card over the C battery terminal screws in exactly the position shown in Fig. *19D*, then replace the battery nuts. When a terminal screw does not fit into a hole in the card, you can either enlarge the hole with a pen knife or, in the case of the Eveready 761-T unit, move the terminal screw a small amount.

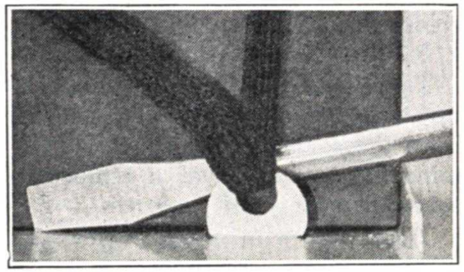


FIG. 19E. Method of holding the lace with a screwdriver while tying the final knot at battery tab *jj*.

Connect a 2-inch length of hook-up wire between the two C battery terminals identified as —4½C on the card, so as to place the two C batteries in series. This wire *must remain in this position* for the entire life of the C batteries.

From now on, all C battery connections will be specified *by the new terminal markings* on the card.

Note: To make a terminal identification card for C batteries obtained elsewhere than from NRI, cut out a piece of stiff paper or smooth carboard having the approximate size of the top area of both C batteries (for two average-size C batteries, the card dimensions will be 2⅞" × 4"). Place this card over the C battery terminals after removing the terminal nuts and washers, and press down on each terminal screw in turn with your thumb or one of the terminal nuts, so the screws will project up through the card. Finally, mark your card in exactly the same way as the card shown in Fig. 19D, using pen and ink or any other means.

Step 9. If necessary, mark your B battery terminals to conform to the markings in Fig. *19D*, since all B battery connections in the future will be specified by these markings. This will usually mean only changing the — marking to —B, which can be done with crayon. With the batteries now securely tied in position, you can turn the chassis upside down whenever necessary during the following experiments, without having the batteries fall off or slide out of position.

IMPORTANT: Lead lengths specified in this lesson are based upon the dimensions of Eveready batteries. If your batteries hav different dimensions, it will be best to disregard specified lead lengths and use the procedure followed by experienced radio men when wiring up a circuit.

GENERAL WIRING PROCEDURE

1. Locate on your apparatus the two terminals between which the wire is to be connected. Use the pictorial or semi-pictorial wiring diagrams as guides.

2. If you have a used piece of wire which will reach between the two terminals, proceed to connect it.

3. If no suitable length is available, connect one end of your roll of wire to one of the terminals. Run the wire over to the other terminal. Cut the wire to the required length, and complete the connection.

EXPERIMENT 17

***Purpose:* To demonstrate that electrons will flow from the cathode to the plate in a vacuum tube when the filament is heated and the plate is placed at a positive potential with respect to the cathode.**

Step 1. To connect your type 1C5GT pentode tube into the circuit shown in Fig. 20A, wherein it is used as a simple diode tube with a plate voltage of 22.5 volts and with your meter connected to measure the plate current, connect together the tube socket, the meter and the batteries according to the circuit shown in Fig. *20B,* in the following manner:

Turn the chassis upside-down, take a 1-inch length of hook-up wire from which you have removed all insulation, and use it to connect together tube socket terminals *3* and *4* with temporary hook joints as shown in Fig. *21A.* Leave these joints unsoldered for the present.

Connect together tube socket terminals *5* and *7* with a 1¾-inch length of hook-up wire; make temporary hook joints but leave them unsoldered.

Take a 4-inch length of hook-up wire, push one end through hole *b* from the top of the chassis far enough to reach terminal *2,* then make a hook joint between the wire and terminal *2,* as shown in Fig. *21A.*

Take a 5-inch length of hook-up wire, push it through hole *e* from the top of the chassis far enough to reach tube socket terminal *3,* then form a hook joint at this terminal.

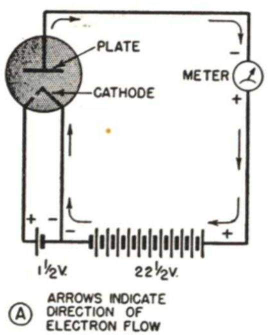
Take a 4½-inch length of hook-up wire, push it through hole *c* from the top of the chassis far enough to reach terminal *7,* then form a hook joint at this terminal.

Now solder the connections to tube socket terminals *2, 3, 4, 5* and *7.*

Turn the chassis over, locate the wire which comes up through hole *e,* and connect it to the soldering lug of meter terminal *16* with a temporary soldered hook joint, as shown in Fig. *21B.*

Take a 10-inch length of hook-up wire and connect one end of it to the soldering lug on meter terminal *15* by means of a temporary soldered hook joint.

Take the wire which comes up through hole *c,* and connect it to the —A terminal of the A battery. Since this terminal has a Fahnestock clip rather than a screw terminal, the connecting procedure is a bit different. First, push the insulation back from



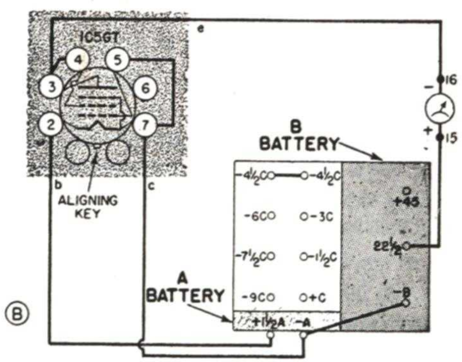


FIG. 20. Schematic circuit diagram *(A)* and semi-pictorial wiring diagram *(B)* for Step 1 of Experiment 17, in which you connect your type 1C5GT tube as a diode. The shaded area around the tube symbol in *B* indicates that connections to the tube socket are under the chassis. The letters e, b and c around this shaded area indicate the chassis holes through which the leads are run.

the end of the lead for about half an inch. Now bend the wire into the position shown in Fig. *21C,* so that the bare end of the wire is directly in front of the center of the Fahnestock clip. Grasp the wire with two fingers of your right hand, press the flat end of the clip with the thumb of your left hand, and insert the wire in the clip just as shown in Fig. *21D.*

In essentially the same manner, take the wire which comes through hole *b* in the chassis and insert it in the +1½A clip from the bottom, as shown in Fig. *21B.*

Take an 8½-inch length of wire, push back the insulation from one end, and insert this end in the —A Fahnestock clip from above, as shown in Fig. *21E,* after first pressing on the flat end of the clip to make room for the wire. (The wire already in the —A clip should stay in position when you press; if it drops, bend the wire upward so it stays in position even when the gripping action of the clip is released by thumb pressure.) Bring the wire from —A diagonally upward

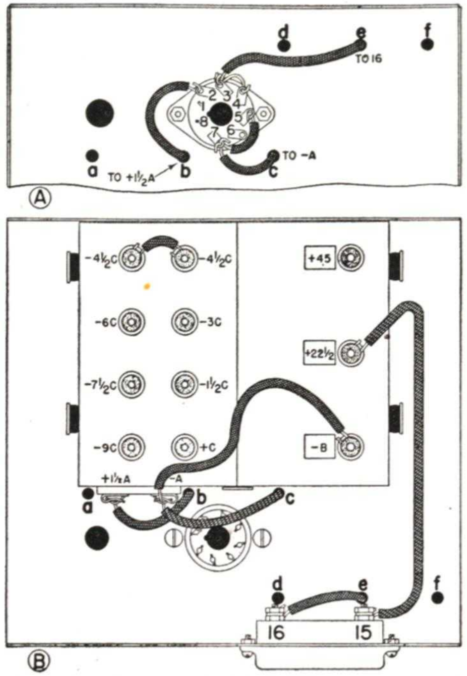


FIG. 21. Under-chassis *(A)* and above-chassis *(B)* connections for Step 1 of Experiment 17.

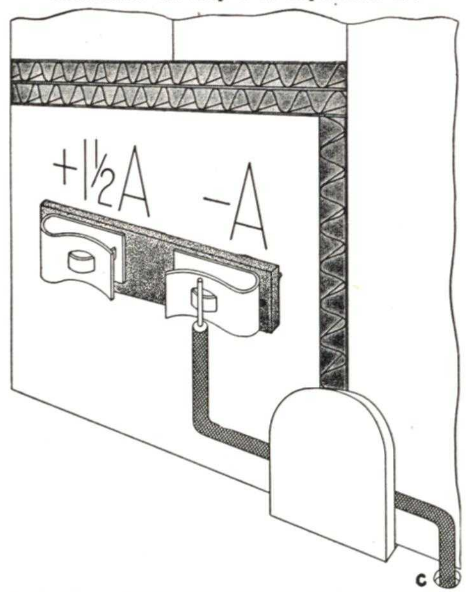
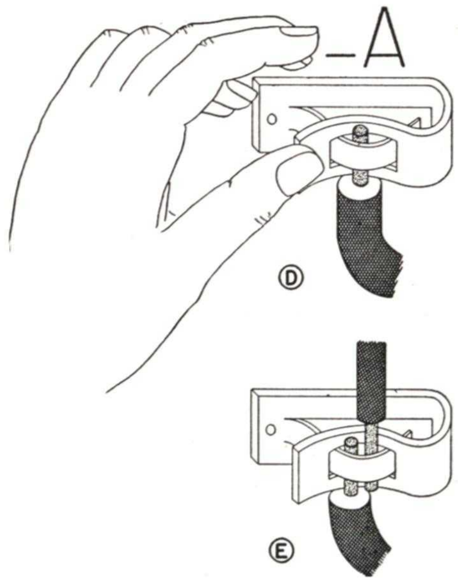


FIG. 21C. When two wires are to be inserted in a Fahnestock clip, bend the first wire so it will stay in this position by itself, before attempting to insert the wire in the clip.



FIGS. 21D and 21E. To insert a wire in a Fahnestock clip, press on the flat end of the clip with your thumb, as shown at *D.* Two wires can readily be placed in one clip, as at *E.*

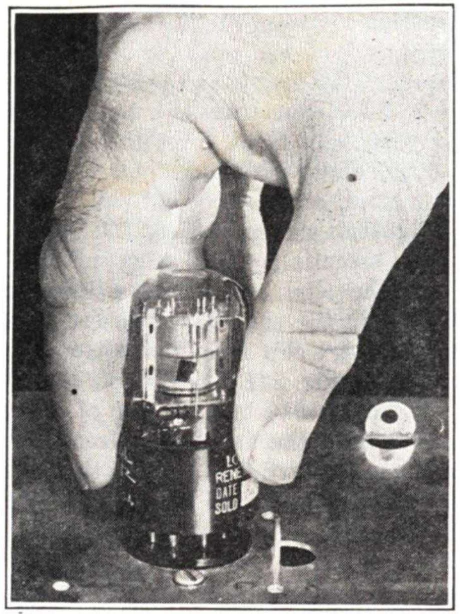


FIG. 21F. Hold a radio tube in the manner shown here when pushing it into or removing it from a socket. Make sure that the aligning key on the tube base is in the aligning slot on the tube socket before attempting to push a tube into its socket. Most of the downward pressure is applied by the thumb and forefinger gripping the base. It may be necessary to apply pressure also on the top of the glass envelope, and rock the tube gently from side to side while pushing downward, for the contacts in a new socket are sometimes a bit stiff. Use the same grip and rocking motion for pulling out the tube.

to the top of the B battery, form a loop on top of the B battery as shown in Fig. *21B*, then connect the wire to the —B terminal. This wire is purposely made longer than necessary, so you can move it to another terminal in Step 3.

Take the lead which you previously soldered to meter terminal *15*, and connect it to the +22½ terminal of the B battery. Watch the meter when you make this connection; there should be no movement of the pointer whatsoever.

Check your work very carefully against the diagrams in Figs. *20B*, *21A* and *21B*, to make sure that every single wire is connected exactly as shown in these illustrations. This final checking of your work is extremely important, for a single error can damage circuit parts or discharge the battery. Do not probe carelessly around the wiring or terminals with a screwdriver or other metal part, for this tool may accidentally short-circuit certain terminals.

Insert the type 1C5GT tube (Part *2-10)* in its socket from the top of the chassis, by first setting the central black aligning pin of the tube base over the central hole in the socket, holding the tube upright while rotating it with the fingers until the aligning key and slot match and the tube drops down, then pushing the tube into its socket in the manner shown in Fig. *21F*.

If you have made all connections properly, the meter pointer should move up-scale when the tube is inserted. Read the meter on scale I_M, and record your reading in the first line of Table *17*.

Step 2. To determine the effect of opening the filament circuit in a diode vacuum tube circuit like that shown in Fig. *20A*, disconnect temporarily the lead which comes up through hole *b* and goes to the +1½A terminal, while watching the meter. Note the meter reading when this lead is disconnected, reconnect the lead, then record your observation in Table *17*. Be very careful that the disconnected lead does not touch either the +45 or the +22½ battery terminal, for this would burn out the tube filament instantly. To prevent burning out the tube while changing the wiring, remove the tube from its socket by grasping with one hand and pulling firmly upward, as shown in Fig. *21F*. It is permissible to wiggle the tube sideways a bit by grasping the base, if removal is somewhat difficult at first.

Step 3. To determine the effect of reversing the plate supply voltage in a diode vacuum tube circuit like that shown in Fig. 20A, interchange the wires which are on the —B and +22½ terminals. In other words, the 10″ lead coming from meter terminal *15* should now go to —B, and the 8½″ lead from the —A terminal should now go to the +22½ terminal.

Replace the tube in its socket, note the meter reading on scale I_M, record your result in Table *17*, then remove the tube from its socket again and return the —B and +22½ leads to their original positions as shown in Fig. *21B*.

STEP	NATURE OF MEASUREMENT	YOUR CURRENT READING ON SCALE I_M IN MA.	N.R.I. CURRENT READING ON SCALE I_M IN MA.
1	PLATE CURRENT IN DIODE CIRCUIT OF FIG. 20A WITH 22½ VOLTS ON PLATE	1.5	2.2
2	SAME AS STEP I, BUT WITH FILAMENT CIRCUIT OPEN	0	0
3	SAME AS STEP I, BUT WITH REVERSED PLATE VOLTAGE	0	0

Table 17. Record your results for Experiment 17 here.

Discussion: In your regular lessons, you learned that a vacuum tube must have at least two electrodes, a *cathode* and a *plate*. The cathode may be heated indirectly by a filament, as it is in tubes you will receive in later kits, or the filament itself may serve as the cathode, as is the case in the type 1C5GT tube you are now using. The electrons which are emitted by the heated cathode move through the vacuum in the tube to the plate when the plate is made positive with respect to the cathode by applying a suitable d.c. voltage. When a tube has only these two electrodes, it is known as a *diode*.

If a coil or spiral of wire is placed between the cathode and the plate in a tube, we have what is known as a *triode* tube, and the additional electrode is known as the control *grid*.

If another grid is placed between the control grid and the plate, we have a four-electrode tube called a *tetrode;* the added electrode is called the *screen grid*.

Finally, if we place still another wire electrode in the tube, between the screen grid and the plate, we have what is known as a *pentode* tube, and this third added electrode is known as a *suppressor grid*.

In the type 1C5GT tube which you now have, all three of these grids—the control grid, the screen grid and the suppressor grid — are present; your tube is therefore basically a pentode. In your tube, however, no terminal prong is provided for the suppressor grid; this grid is permanently connected to the cathode inside the tube. The suppressor grid in the type 1C5GT tube serves to repel slow-speed electrons which "bounce off" the plate due to secondary emission, thereby forcing them back to the plate.

In this experiment, we are interested only in the behavior of the tube as a diode. We can eliminate the effect of the control grid by connecting it to the cathode (connecting together tube socket terminals *5* and *7* does this), and we can eliminate the effect of the screen grid by connecting it to the plate (connecting together tube socket terminals *3* and *4* does this). Although we cannot change the internal connection of the suppressor grid, we can ignore the effects of this grid for the present, since they are relatively unimportant in this experiment.

By connecting grids to either the cathode or the plate in this manner, any multi-element vacuum tube can be adapted for use as a simple diode.

The fact that you obtain a meter reading for the first step in this experiment shows that electrons will flow through a vacuum tube in the direction from the cathode to the plate when the cathode is heated and the plate is charged positively with respect to the cathode. We know the electrons take this direction because we previously found (Experiment 11) that the meter gives an up-scale deflection when electrons enter the minus terminal of the meter. If you trace around the plate circuit of Fig. *20A* in the direction which makes the electrons enter the minus terminal of the meter, you will find that electron flow is in the direction indicated by arrows, and is therefore from the cathode to the plate through the tube.

The exact value of plate current obtained in Step 1 is not particularly important, and your value will very likely differ considerably from the reading which we obtained. This is perfectly normal, and is due simply to the fact that different tubes, batteries and radio parts will vary considerably in their characteristics. In all measurements which you make in vacuum tube circuits, remember this fact, and do not expect to obtain values which agree closely with the NRI readings.

The important thing for you to recognize is that *your readings should increase when ours do, and your readings should decrease, or drop to zero, when our readings do this.* In other words, your readings should verify basic radio principles by the *manner* in which they increase or decrease, rather than by agreeing with any specific values.

When you disconnect the filament circuit by removing the lead from the +1½A terminal, you interrupt the flow of current through the filament of the tube. As a result, the filament cools to normal room temperature, and ceases emitting electrons. Without electron emission, no electrons can flow to the plate, and consequently the plate current should drop to zero for Step 2.

When you reverse the B battery connections in Step 3, you make the plate negative with respect to the cathode. Under this condition, the plate repels rather than attracts electrons, forcing the emitted electrons to return to the cathode without getting anywhere.

The fact that the meter pointer is at zero with reversed plate voltage also tells that reversing the plate voltage source will *not* reverse the direction of electron flow. If it did, you would observe an off-scale movement of the pointer to the left of zero. Electrons cannot flow in a reverse direction through a vacuum tube because the plate is not heated and cannot emit electrons.

From a technical standpoint, we can consider the cathode-plate path in our vacuum tube to be a resistance. Furthermore, we can consider that the value of this resistance may be either high or low, depending upon the polarity with which the plate voltage supply is connected; with correct polarity as in Step 1, we obtained a definite current value, and with reverse polarity as in Step 3, we obtained no current (no current means that the tube has an infinitely high resistance).

Computing Circuit Current. In the diode vacuum tube circuit of Fig. *20A*, we have a 22.5-volt battery and a 2,000-ohm meter in series with the cathode-plate path through the tube. If this tube path were shorted or if it had zero resistance, the total circuit resistance would be 2,000 ohms and the plate circuit current would be 22.5 divided by 2,000, which is .01125 ampere, or 11.25 ma. Actually, we measure only about 2 ma. of plate current in Step 1 of this experiment; the only way to explain this is by assuming that the tube has resistance.

For computation purposes, let us assume that we obtain a plate current reading of 2 ma. With the aid of Ohm's Law, now we can determine what the resistance of the tube actually is. By dividing 22.5 by .002, we get 11,250 ohms as the total resistance of the plate circuit. Since 2,000 ohms of this is already in the meter, the remainder or 9,250 ohms must be the plate-cathode resistance in this direct current circuit. This resistance is comparatively low, and consequently we can say that the type 1C5GT tube has good conducting ability when its plate is positive with respect to the cathode. In some specially designed diode rectifier tubes employed in radio receivers, the d.c. resistance value may be as low as 100 ohms.

When the plate was made negative with respect to the cathode, you found that no current flowed. This condition could exist only if the tube had an infinitely large resistance, and behaved like an open circuit.

Practical Extra Information. You already know that an a.c. voltage is equivalent to a repeated and regular reversal in the polarity of a d.c. voltage. Therefore, if an a.c. voltage is employed in the plate circuit of Fig. *20A* in place of the 22.5-volt B battery, the plate will be alternately positive and negative with respect to the cathode.

This experiment shows, however, that current will flow in the plate circuit only when the plate is positive with respect to the cathode. This means that when we apply an a.c. voltage to the plate, we will have a pulsating direct current in the plate circuit, with electrons flowing only in one direction. This is the basic principle of the power packs used in radio receivers to convert alternating current to direct current. In later experiments, you will actually demonstrate this important principle of rectification.

Multi-element vacuum tubes like that which you now have are actually being used as diode tubes in some types of radio equipment. For instance, some manufacturers often use a triode tube as a diode by connecting the control grid to the plate. Also, in emission-type tube testers, all grids of the tube under test are connected automatically to the plate, and the resulting plate current for a diode connection is measured at a suitable plate voltage value. If the tube is in good condition, the measured value of plate current will be normal, and the tube tester will indicate "GOOD."

Instructions for Report Statement No. 17. After you have completed this experiment and studied the discussion, measure the plate current through your diode-connected vacuum tube when there is an 18,000-ohm resistor in the plate circuit. To do this, start with your apparatus arranged just as it was at the end of Step 3 (so all connections are exactly as shown in Figs. *21A* and *21B*). Remove the wire from the +22½ terminal, solder one lead of the 18,000-ohm resistor to this wire by means of a temporary lap or hook joint, then place the other resistor lead on the +22½ terminal after first bending a hook in its end. Insert the tube in its socket, read the meter on scale I_M, and record your result in Report Statement No. 17 as the plate current in ma. when an 18,000-ohm plate load is used. Now remove the tube, disconnect the 18,000-ohm resistor, and reconnect the lead from *15* to the +22½ terminal.

EXPERIMENT 18

***Purpose:* To demonstrate that the grid voltage in a vacuum tube has more control over plate current than does the plate voltage.**

Step 1. To determine what happens to the plate current when the plate voltage is increased from 22.5 volts to 45 volts in a single diode vacuum tube circuit, first take a 910 ohm resistor (Part *2-14*) and connect it between meter terminals *16* and *15* to serve as a shunt which will increase the current range of the meter three times, as shown in Fig. *22.* This connection can be made by bending a hook in one resistor lead, tinning the hook liberally, then holding the hook over the soldering lug of meter terminal *16* with one hand while applying the heated soldering iron to the joint with your other hand. Now simply make a soldered lap joint between the other resistor lead and meter terminal lug *15.* You can do this without removing the batteries from the chassis.

With all other connections exactly as they were for Step 1 of Experiment 17 (with the 10-inch lead from

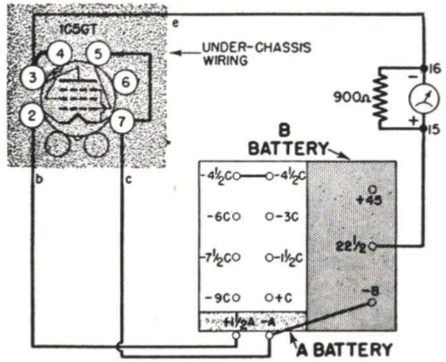
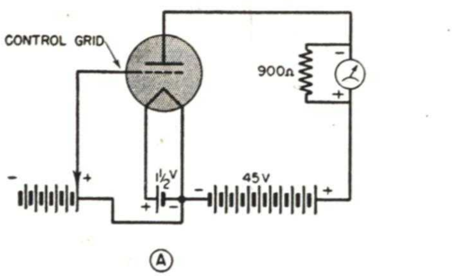


FIG. 22. Semi-pictorial wiring diagram for Step 1 of Experiment 18, in which you change the plate voltage on a diode tube from 22½ volts to 45 volts and note the effect upon plate current.

terminal *15* going to +22½ as shown in Figs. *21A* and *21B*), insert the tube in its socket, read the meter on scale I_M, and record your reading on the first line of Table *18.* Multiply this reading by 3 to get the plate current value in ma., and record this answer also on the first line of Table *18.*

Now increase the plate voltage to 45 volts by removing the lead from



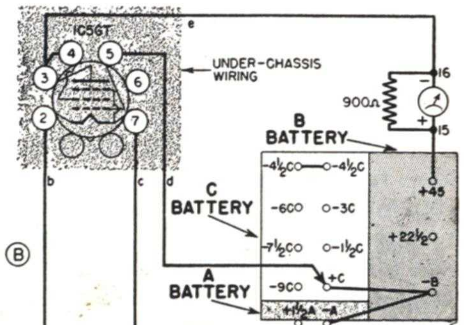


FIG. 23. Schematic *(A)* and semi-pictorial *(B)* diagrams for the triode vacuum tube circuit which you set up for Step 2 of Experiment 18.

STEP	PLATE VOLTAGE IN VOLTS	C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT VALUE IN MA. (METER READING X 3)	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT VALUE IN MA. (METER READING X 3)
1	22.5	0	.5	1.5	.8	2.4
	45	0	2.5	7.5	2.5	7.5
2	45	0	2.5	7.5	2.5	7.5
	45	0	1.6	4.8	.6 (C BIAS = -4.5V)	1.8

TABLE 18. Record your results for Experiment 18 here.

the +22½ terminal and placing it on the +45 terminal. There is no need to remove the tube while doing this. Read the meter on scale I_M, record your results (first the meter reading, then the actual current value in ma.) on the second line of Table *18,* then remove the tube from its socket.

Step 2. To determine how much more effective the control grid is than the plate in controlling plate current, connect your type 1C5GT tube as a triode in the circuit shown in Figs. *23A* and *23B,* proceeding as follows:

Turn the chassis over carefully, and unsolder completely the 1¾-inch lead which connects together tube socket terminals *5* and *7.* Save this lead for future use.

Take a 13-inch length of hook-up wire, push it almost completely through chassis hole *d,* and connect the exposed end of this lead to tube socket terminal *5* by means of a soldered temporary hook joint, as shown in Fig. *24.* Do not disturb any other connections under the chassis. Note: If using other makes of batteries, this lead on terminal *5* must be made long enough to reach all terminals on the C battery.

Carefully set the chassis upright again while holding the battery in position, locate the other end of the long lead coming up through hole *d,* and connect it to the +C terminal of your C battery, as shown in Fig. *24B.*

With a 7-inch length of hook-up wire, connect the +C terminal to the —B terminal, as in Fig. *24B.* This wire is purposely made longer than

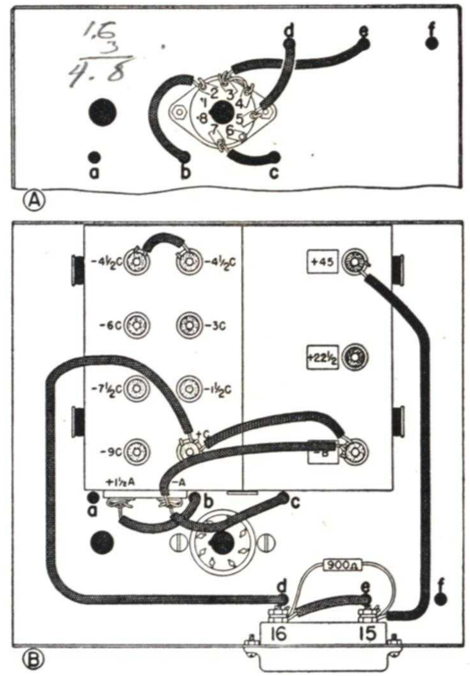


FIG. 24. Connections under the chassis for Step 2 in Experiment 18 should be as shown at *A.* The changes involved are as follows: Remove the lead which connects terminals 5 and 7, then bring a lead through hole *d* and connect it to terminal 5. Connections above the chassis should be changed to those shown at *B.* You now use the C battery terminals for the first time.

necessary, so it can be moved to other terminals later.

You have now duplicated the circuit presented in Fig. *23*. Check your work carefully against the semi-pictorial circuit diagram in Fig. *23B* before proceeding further.

Insert the tube in its socket, read the meter on scale I_M for this condition whereby the plate voltage is 45 volts and the control grid voltage is 0 volts with respect to the cathode, and record your results (first the meter reading, then the actual current in ma.) on the third line in Table *18*.

Now remove the 13-inch lead (the lead coming through hole *d*) from the +C terminal and place it in turn on —1½C, —3C, —4½C, —6C and —7½C until you find the terminal which gives a meter reading *nearest* the first meter reading you obtained in Step 1 (nearest the reading obtained for a plate voltage of 22.5 volts). If one terminal gives too much plate current but the next negative terminal gives too little current, select the terminal which gives nearest the desired plate current. Record on the last line of Table *18* the C bias voltage value as marked on this terminal, the resulting meter reading on scale I_M, and the actual current value in ma. (three times meter reading).

Remove the tube from its socket, but leave all wiring as it is for the present.

Discussion: Since in this experiment we expect to deal with current higher than 3 ma., the first thing we do in Step 1 is place across the meter a 910-ohm shunt resistor which increases the meter range approximately three times.* We then read the meter on scale I_M and multiply each reading by 3 to get the true current value in ma.

In Step 1, you measured the plate current of the diode tube with your meter first for a plate voltage of 22.5 volts, then for a plate voltage of 45 volts. One important fact to remember in these two measurements is that increasing the plate voltage makes the plate current *increase*.

In Step 2, you kept the plate voltage at 45 volts and determined how much voltage was required on the control grid in order to make the plate current drop to the first current value measured in Step 1 (corresponding to 22.5 volts on the plate).

As Table *18* indicates, we found in the NRI laboratory that it took only about 4.5 volts of change in the control grid voltage (from the zero grid voltage value of the first reading in Step 2 to the —4.5 volt grid voltage value of the second reading in Step 2) to reduce the plate current the same amount as did a 22.5-volt change in the plate voltage (from +45 to +22.5). In other words, we found that 4.5 volts of variation in the control grid voltage had just as much effect upon plate current as did 22.5 volts of variation in the plate voltage.

Considering basic vacuum tube action now, we naturally expect that as we make the grid increasingly more negative with respect to the cathode, it repels electrons more and more. This is exactly what we demonstrated in this experiment—that increasing the negative grid voltage cut down the plate current.

The NRI values indicate that a 4.5-volt change in grid voltage (from zero to —4.5) had as much effect upon plate current as a 22.5-volt change in plate voltage. We secure the number 5 when we divide 22.5 by 4.5; this indicates that the grid in the tube is five times more effective than the plate in controlling plate current. In technical language, we say that the amplification factor of the tube is 5 for the conditions in the NRI laboratory.

Schematic circuit diagrams tell which terminals are to be connected together. Semi-pictorial and pictorial diagrams also tell *how* these terminals should be connected together for best results (for maximum convenience, minimum wire lengths, or to anticipate possible future changes). The rule to remember is that a group of terminals can be connected together in many different ways, all of which give the same electrical results. Thus, instead of running a lead from +C to —B in Step 2, you would get the same results (though not so convenient a connection) by connecting +C to —A.

Practical Extra Information. The closer the grid is to the cathode in a vacuum tube and the closer the turns of wire in the coiled grid are to each other, the greater is the control which the grid has over plate current.

With an elaboration of the measuring technique employed in this experiment, we can determine quite accurately the amplification factor of any vacuum tube. We would do this by varying the plate voltage enough to cause a convenient change in plate current, then vary the grid voltage exactly enough to cause this same variation in plate current. In each case, we would make accurate measurements of the voltages involved, then divide the plate voltage variation by the grid voltage variation to secure the amplification factor of the tube.

The fact that the grid is a certain number of times more effective than the plate in a vacuum tube means that we can employ the tube to build up the strength of signals. In other words, we can supply a small a.c. voltage to the grid and secure a much larger pulsating plate current which is equivalent to a larger a.c. voltage in series with the d.c. plate voltage. With a coupling condenser or coupling transformer, we can transfer this a.c. voltage alone to another circuit for further amplification or for feeding to a loudspeaker or other device.

It is this superior ability of the grid to control plate current which makes vacuum tubes suitable for use in amplifiers and oscillators. You will learn more about these special vacuum tube circuits later.

Instructions for Report Statement No. 18. Make one additional measurement with the triode vacuum tube circuit of Figs. *23* and *24*. Use a plate voltage of 45 volts and a C bias of —3 volts, with the grid return lead from +C first connected normally to —A (by means of wires going from +C to —B and from —B to —A), then with the grid return lead connected to +1½A, and note what the plate current is in each case. (Here are more detailed instructions: Start with your circuit connected *exactly* as shown in Fig. *24*. Take the lead which comes out of hole *d* and move it from +C to —3C to get a C bias of —3 volts. The grid return lead (going across the battery from +C) is already on —B, and —B is already connected to —A, so read the meter to get the plate current value. Now remove from —B

* Actually, a 910-ohm shunt increases the range of a 2,000-ohm meter 3.2 times, but because of normal deviations in meter characteristics and resistor values during manufacture, we can, for all practical purposes, consider this scale multiplication factor to be 3.

the lead which goes to +C, connect this lead to +1½A so that +C and +1½A are connected, and again read the meter to get the plate current value.)

Turning next to Report Statement No. 18 on the last page, place a check mark after the answer which describes the change you observed in the plate current value when the grid return lead was on +1½A.

From this extra test, you can make your own conclusions as to the importance of placing the grid return lead on a particular filament terminal when working with filament-type tubes such as the 1C5GT. The principles involved are covered in the lessons on power supplies in your fundamental course.

Put the grid return lead back on –B, so that –B is again connected to +C, and remove the tube from its socket. Leave all other wiring as it is until you are ready to start the next experiment.

EXPERIMENT 19

***Purpose:* To demonstrate that a grid in a vacuum tube draws a current when it is positive with respect to the cathode, but does not draw current when negative with respect to the cathode.**

Step 1. To secure plate current reading for different positive and negative values of C bias voltage when your vacuum tube is connected as a triode in the circuit of Fig. *25A,* use the semi-pictorial wiring diagram in Fig. *25B* and the top-of-chassis pictorial diagram in Fig. *26* as your guides for rewiring the vacuum tube circuit for this experiment. Connections under the chassis are left the same as for the previous experiment, and are therefore still as shown in Fig. *24A*.

The changes required above the chassis for this experiment are as follows: Disconnect the 7-inch lead from +C, and connect it to –7½C, so that –7½C is now connected to–B.

Now disconnect from –3C the lead coming up through hole *d*, wind its bare end about twice around one straight lead of the 6.8-megohm resistor (Part *2-11*) as shown in Fig. *26*, and solder this temporary joint. Connect the other lead of this resistor to battery terminal –9C, so as to provide a C bias voltage of –1.5 volts.

Insert the tube in its socket, read your meter on scale I_M, and record your results on the first line of Table *19* as the plate current reading for a –1.5 volt C bias and 6.8 megohm grid circuit resistance. *Note:* Since the 910-ohm shunt is still across the meter, you must multiply each meter reading on scale I_M by 3 to get the plate current value in ma. Record the meter reading first in the space provided for this purpose in Table *19*, then multiply the reading by 3 and jot down your answer in the other space provided on the same line in the table.

Now take one of your test leads, attach its alligator clip to one lead of the 6.8-megohm resistor, and touch its test probe to the other resistor lead in the manner shown in Fig. *27*, so as to short out the resistor. Read the meter on scale I_M, and record your results (the meter reading and the current in ma.) on the second line of Table *19* as the plate current for the condition of –1.5 volts C bias and *zero* grid circuit resistance. Remove the test probe and allow it to rest on the table now without touching the chassis or any other part of the circuit, but leave the alligator clip on the other resistor lead.

Remove the lead of the 6.8-megohm resistor from the –9C terminal and connect this lead now to the –7½C terminal without changing any other connections. Read the meter on scale I_M and record your results on the third line of Table *19* as the plate current for zero C bias voltage and a grid circuit resistance of 6.8 megohms.

Now short out the 6.8-megohm re-

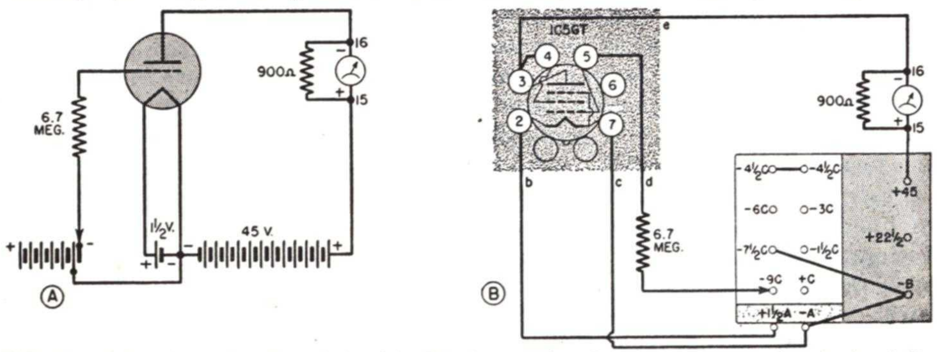


FIG. 25. Schematic *(A)* and semi-pictorial *(B)* diagrams for the triode vacuum tube circuit of Experiment 19. Note: Use the 6.8-megohm resistor sent you as Part 2-11 in place of the 6.7 meg. shown.

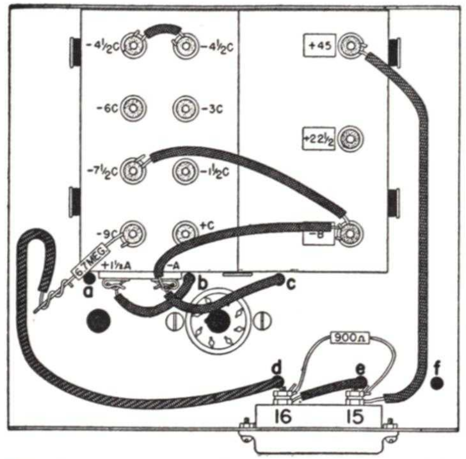


FIG. 26. Connections above the chassis should be modified to appear exactly as shown in this view, before starting to make measurements for Experiment 19.

C BIAS VOLTAGE IN VOLTS	GRID CIRCUIT RESISTANCE IN MEGOHMS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT VALUE IN MA. (METER READING X 3)	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT VALUE IN MA. (METER READING X 3)
–1.5	6.7	2.6	7.8	1.8	5.4
–1.5	0	3	1.5	1.8	5.4
0	6.7	2.5	7.5	2.5	7.5
0	0	2.5	7.5	2.5+	7.5+
+1.5	6.7	1.7	5.1	2.7	8.1
+1.5	0	1.6	4.8	3+	9+
+3	6.7	1	.3	2.7	8.1
+4.5	6.7	1.8	5.4	2.7	8.1

TABLE 19. Record your results for Experiment 19 here. A "+" sign *following* a value indicates that it was slightly *more* than the value given.

sistor temporarily with the test lead, read the meter on scale I_M, and record your results in Table *19* as the plate current for zero C bias and zero grid circuit resistance. Now remove the short across the resistor.

Remove the lead of the 6.8-megohm resistor from the —7½C terminal and place this resistor lead on the —6C terminal. Read the meter on scale I_M, record your results in Table *19* as the plate current for +1.5 volts C bias and a grid circuit resistance of 6.7 megohms.

FIG. 27. Method of using a test lead to short out temporarily the grid resistor employed in Experiment 19.

Now short the resistor with the test lead, read the meter on scale I_M, and record your results in Table *19* as the plate current for +1.5 volts C bias and zero grid current resistance. Now remove the test lead entirely from your circuit, since it will no longer be used in this experiment.

Remove the lead of the 6.8-megohm resistor from the —6C terminal, and place this lead on the —4½C terminal. Read the meter on scale I_M, and record your results in Table *19* as the plate current for +3 volts C bias and 6.8 megohms grid circuit resistance. The resistor should not be shorted when this C bias voltage is used because this would make the meter read off-scale.

Remove the lead of the 6.8-megohm resistor from the —4½C terminal and place this lead on the —3C terminal. Read the meter on scale I_M, and record your results in Table *19* as the plate current for 4.5 volts C bias and 6.7 megohms grid circuit resistance. Now remove the vacuum tube from its socket.

Discussion: For your first measurement, in this experiment, you make the grid 1.5 volts negative with respect to the cathode by connecting the cathode (filament) to the —7½C terminal of the C battery and by connecting the grid to the —9C terminal, which it 1.5 volts negative with respect to the —7½C terminal. (Instead of saying that the grid is 1.5 volts negative with respect to the cathode, technicians commonly say that they are using a *—1.5 volt C bias*, or a grid voltage of —1.5 volts.)

When the grid is made negative in this manner, it repels rather than attracts electrons, and consequently there is no electron flow in the grid circuit. You proved this by shorting the grid circuit resistance; if grid current did exist, it would flow through the grid resistor and produce across this resistor a voltage drop. Shorting of the resistor would remove this voltage drop from the grid circuit and change the resultant voltage on the grid, making the plate current change.

You found, however, that shorting of the grid resistor did not noticeably affect the plate current as indicated by the meter; this means that no grid current was flowing in your circuit. Actually, the grid-cathode path in a tube acts as an infinitely high resistance when a negative C bias is used, just as does the plate-cathode path when the plate is made negative with respect to the cathode (you proved this latter statement in Step 3 of Experiment 17).

Careful inspection of your circuit when you connect the resistor lead to the —7½C terminal will show you that now both the grid and the cathode of your tube are connected to the same terminal. This means that you are employing zero C bias, and the grid is therefore at cathode potential. Under this condition, the grid neither attracts nor repels electrons, and again we would expect that there would be no appreciable amount of grid circuit current. We obtain a higher plate current reading for zero bias than for —1.5 volts bias, simply because more electrons can get through the grid wires to the plate when the grid is no longer repelling them.

When using zero C bias, you again find that shorting the grid resistor has no great effect upon the meter reading. This proves definitely that there is no appreciable amount of grid circuit current flowing.*

When you make the grid 1.5 volts positive with respect to the cathode by connecting the resistor lead to the —6C terminal (this terminal is 1.5 volts positive with respect to the —7½C terminal to which the cathode is connected), the grid attracts some of the electrons which are emitted from the cathode. Those electrons which reach the grid travel through the 6.8-megohm grid circuit resistor in their way to the C bias battery, developing across this resistor a voltage drop which acts in series with that provided by the C bias battery but is of opposite polarity.

In other words, the voltage drop across the resistor neutralizes the voltage provided by the C bias battery, reducing the positive C bias value which is actually acting on the grid. As a result, the grid-cathode path through the tube does not get the full voltage provided by the C battery when the resistor is in the circuit. Cutting out the grid resistor proves this fact, for with the resistor removed, the meter reading increases noticeably.

Increasing the positive C bias to 3 volts, with the 6.8-megohm resistor in the grid circuit, does not give any more plate current than did a +1.5 volt C bias. The reason for this is simply that making the grid more positive in this manner causes it to attract more electrons, and the resulting increase in electron flow through the grid resistor increases the voltage drop across this resistor and completely neutralizes the increase in C bias voltage. We secure the same

* You may note a slight increase in the meter reading when shorting the resistor while using zero bias. This is due chiefly to a contact potential which exists between dissimilar metals in the grid circuit and in the grid lead inside the tube; this contact potential makes the grid slightly positive with respect to the cathode when the grid resistor is shorted out. Another reason for the increase is the fact that some electrons will be headed straight for grid wires and will hit these wires. When the grid resistor is present, these electrons travel through it and develop across it a small negative C bias. Shorting the resistor shorts out this bias, thus making the grid swing a small amount more positive.

On the other hand, you may note a slight decrease in the meter reading due to gas in the tube or to dirt between tube terminals. If wiping the tube base and tube socket with a cloth has no effect, continue with your experiments. Small decreases (or increases) in the meter reading can be overlooked.

effect with a +4.5 volt C bias; in other words, all positive C bias voltages give essentially the same plate current reading when the 6.8-megohm resistor is in the circuit.

Of course, removing the resistor would allow the full voltage of the C battery to be applied to the grid; we cannot do this for the +3 and +4.5 volt bias values, however, because the resulting plate current would be way higher than the range of our meter, and would possibly damage the meter and the tube.

Practical Extra Information. In some radio circuits, both positive and negative C bias voltages are applied to the grid. There is no objection to this practice as long as the vacuum tube is designed to handle high plate current values and the grid circuit is so designed that it will not distort the radio signal. Whenever the grid circuit draws current, the source of grid voltage must supply a certain amount of power.

As a general rule, the control grids of the vacuum tubes employed in radio receivers are seldom driven positive, and therefore grid current is seldom present. An exception to this occurs in the case of certain power output tubes, which are intentionally driven positive to obtain increased audio output power.

Another exception occurs in the case of oscillator circuits; here the grid often is purposely allowed to become positive, but the circuit itself is so designed that it introduces automatically a negative bias which keeps the plate current down to a safe and useful value. This is done simply by employing the proper value of grid resistor, for as you learned in this experiment, a grid resistor can develop a voltage which will counteract an applied positive voltage on the grid.

We will use this same grid resistor scheme in the NRI Tester as a precaution against damage to the tube and meter in the event that the grid of the tube is accidentally driven positive.

Instructions for Report Statement No. 19. After completing this experiment and studying the discussion, take one additional reading. With your apparatus set up as it was for the last measurement in this experiment (with the 6.8-megohm grid resistance in the circuit, a plate voltage of 45 volts, and a C bias of +4.5 volts obtained by having the grid resistor lead on —3C while —B is connected to —7½C), reduce the plate voltage from 45 volts to 22.5 volts by moving the plate lead (the lead which goes to meter terminal *15*) from +45 to +22½. Read the meter on scale I_M and record the value in Report Statement No. 19, then multiply your value by 3 to get the actual plate current in ma. for 22.5 volts on the plate, and record this also in the report statement. Finally, pull out the tube.

EXPERIMENT 20

***Purpose.* To secure data and prepare graphs which will show the grid voltage-plate current characteristics of your type 1C5GT vacuum tube when connected as a triode and when connected as a pentode under three different sets of operating conditions.**

Step 1. To secure the E_g-I_p characteristic curve for your tube when operated as a triode with a plate voltage of 45 volts, reconnect the tube and battery into the circuit shown in Fig. *23.* The connections are shown in pictorial form in Fig. *24*, but by now you should be able to follow semi-pictorial diagrams like that in Fig. *23B* and depend upon the photographs and

pictorial diagrams only for checking purposes. For the first reading, set the C bias at —9 volts by placing on terminal —9C the lead which comes from chassis hole *d* (this lead is shown on +C in Fig. *23B*). Read the meter on scale I_M, and record your results (both the meter reading and the actual current in ma., which is three times the meter reading) on the first line of Table *20A* as the plate current for a C bias voltage of —9 volts.

Move the control grid lead (the one coming from hole *d*) in turn to —7½C, —6C, —4½C, —3C, —1½C and +C, read the meter on scale I_M in each case, and record the meter readings and the actual current values on the correct lines in Table *20A*. Since the cathode of the tube is connected to +C in this case, the battery markings are also the C bias voltages, with +C giving zero C bias voltage because the cathode is also connected to +C. In other words, when the lead from *d* is connected to —4½C, you are using a C bias voltage of —4.5 volts.

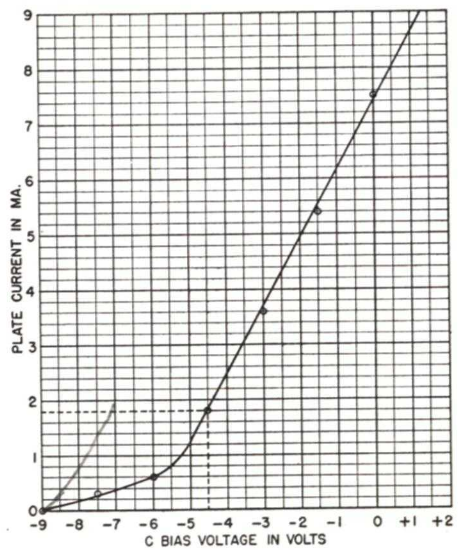
To secure a positive C bias voltage of 1.5 volts, remove from +C the lead which goes to —B, and connect this lead instead to —1½C, so —B and —1½C are now connected together. Leave the control grid lead on +C. Read the meter on scale I_M, and record your result in Table *20A* as the plate current for a bias voltage of +1.5 volts.

You now have meter readings for C bias voltages ranging from —9 volts to +1.5 volts in 1.5-volt steps. Plot these values on Graph *20A* to secure the E_g-I_p characteristic curve for your tube when used as a triode. Do this in the following manner for each measured value:

Locate on the vertical scale at the

C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT IN MA.	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT IN MA.
-9	2.5	7.5	0	0
-7.5	1.6	4.8	.1	.3
-6	1	.3	.2	.6
-4.5	.4	1.2	.6	1.8
-3	1	.3	1.2	3.6
-1.5	1.6	4.8	1.8	5.4
0	2.5	7.5	2.5	7.5
+1.5	3+	9+	3+	9+

TABLE 20A. Record your results for Step 1 of Experiment 20 here. Corresponding values which were obtained in the NRI laboratory, along with the curve representing these values on the graph at the right, are presented here merely for comparison purposes. Your own values may be different.



GRAPH 20A. Plot on this graph the results you obtain in Step 1 of Experiment 20, and connect the points together to give a smooth curve. This will then be the characteristic curve of your type 1C5GT tube when operated as a triode with a plate voltage of 45 volts and no plate load.

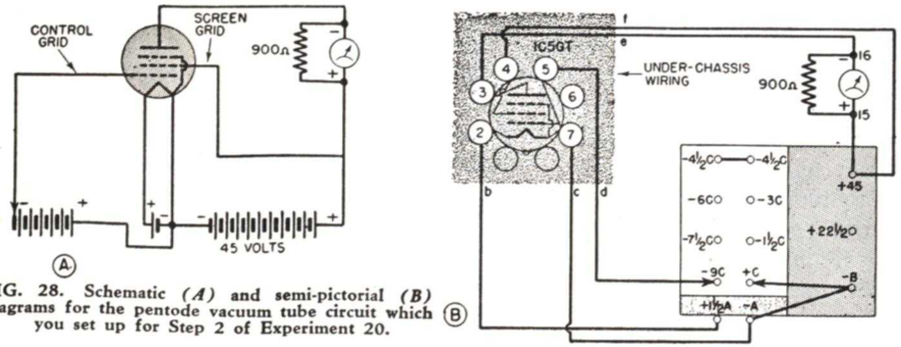


FIG. 28. Schematic *(A)* and semi-pictorial *(B)* diagrams for the pentode vacuum tube circuit which you set up for Step 2 of Experiment 20.

left the measured plate current value in milliamperes. Draw a light horizontal pencil line across the entire graph, passing through this current value on the scale. Now locate on the horizontal scale at the bottom of the graph the C bias voltage which gave you that current value, and draw a vertical pencil line upward from this C bias value. Where the two lines intersect, make a dot with your pencil. This dot now represents the current reading obtained for the C bias voltage in question.

In the same manner, plot on this graph each other reading which you obtained in Step 1. After you have plotted a few values, you will find that you can trace along the horizontal and vertical lines with your pencil and place the dots in their correct positions without actually drawing in the horizontal and vertical pencil lines. Finally, draw a smooth freehand curve which passes through or near the dots which you placed on the graph.

To illustrate this process of plotting values on a graph, we have plotted with small circles connected by a thin solid line the results obtained in the NRI laboratory for this experiment. The horizontal and vertical lines for one point, corresponding to a C bias voltage of 4.5 volts and our plate current reading of 1.8 ma., are indicated as dash-dash lines to show you how they are used to locate a point on the graph. *You are not expected to get the same values or the same curve.*

Step 2. To secure the E_g-I_p characteristic curve for your pentode tube when operated in the circuit shown in

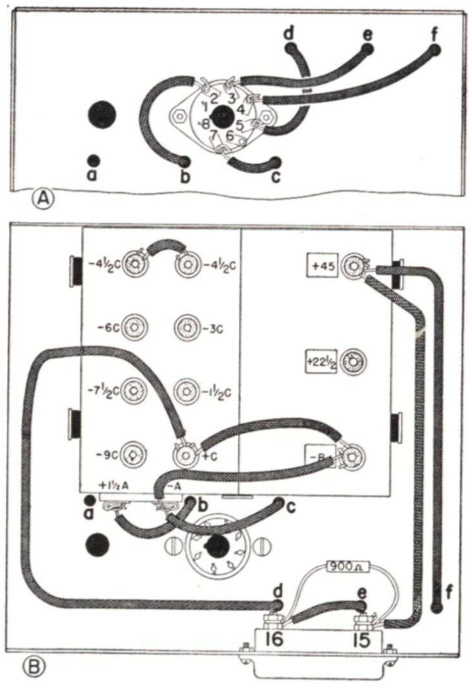


FIG. 29. Connections under the chassis for Step 2 of Experiment 20 should be as shown at *A*. Since the parts under the chassis are now wired according to Fig. *24*, simply remove the wire which connected terminals *3* and *4*, and run a wire through chassis hole *f* to terminal *4*. Battery connections are shown at *B*. Note that while the grid lead is shown on +C, the first measurement is made with a bias of —9 volts. See Fig. *28*.

28A, so that 45 volts is applied directly to the screen grid and the same 45 volts is applied to the plate through the 2,000-ohm meter shunted by the 910-ohm resistor, remove the tube from its socket and change the wiring of your circuit in accordance with the semi-pictorial diagram in Fig. *28B*. This will make the wiring appear as shown in Figs. *29A* and *29B*. Only two changes are necessary under the chassis; the bare wire which connected tube socket terminals *3* and *4* is removed, and a 14-inch long wire is brought through hole *f* and connected to tube socket terminal *4* by means of a soldered temporary hook joint. Above the chassis, the changes involved are connecting to the +45 battery terminal the wire which comes up through hole *f*, and moving the lead on —1½C back to +C.

For the first reading, place the control grid lead (coming up from hole *d)* on terminal —9C. Insert the tube in its socket, read the meter on scale I_M, and record your results in Table *20B* as the plate current for a C bias voltage of —9 volts. (Remember that the meter readings on scale I_M must be multiplied by 3 to get the current in ma. when the 910-ohm shunt resistor is being used across the meter.)

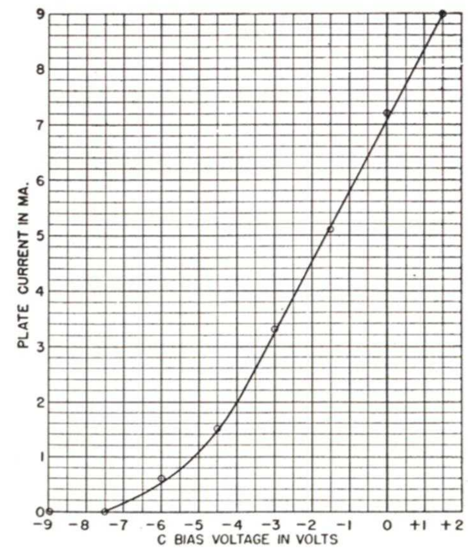
Move the control grid lead (coming through hole *d)* in turn to —7½C, —6C, —4½C, —3C, —1½C and +C; read the meter in each case and record your results in Table *20B*. The value marked on the battery terminal will be the C bias voltage in these cases, since the cathode is connected to +C.

To secure a C bias of +1.5 volts, connect now to +C the wire from hole *d*. Remove from +C the lead which goes to —B, and connnect this 7-inch lead instead to —1½C. Read the meter on scale I_M, and record your results in Table *20B*.

Plot your results for Step 2 on

C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT IN MA.	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT IN MA.
-9	2.5	7.5	0	0
-7.5	1.5	4.5	0	0
-6	.9	1.8	.2	.6
-4.5	.3	.9	.5	1.5
-3	.9	1.8	1.1	3.3
-1.5	1.5	7.5	1.7	5.1
0	2.5	7.5	2.4	7.2
+1.5	3.0	9.0	3.0	9.0

TABLE 20B. Record your results for Step 2 of Experiment 20 here. Remember that your own values are not expected to be the same as the NRI values given here for comparison purposes.



GRAPH 20B. Plot on this graph the results you obtain in Step 2 of Experiment 20, and connect the points together to give a smooth curve. This will then be the characteristic curve of your type 1C5GT tube when operated as a pentode with plate and screen grid voltages of 45 volts; no plate load.

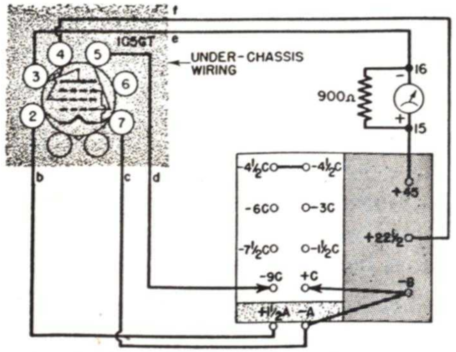


FIG. 30. Semi-pictorial wiring diagram showing all connections for Step 3 of Experiment 20. The only changes required to make your set-up coincide with this are moving of the screen grid lead (coming through hole *f)* from +45 to +22½, and returning to +C the lead coming from —B.

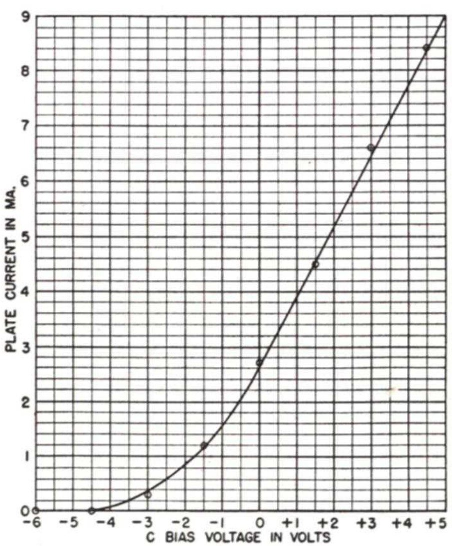
Graph *20B*, then draw a smooth curve passing through or near your points.

Step 3. To determine the effect of a lower screen grid voltage value upon the E_g-I_p characteristic curve of a pentode tube being operated with a plate voltage of 45 volts, move the screen grid lead (coming up through hole *f)* from the +45 terminal to the +22½ terminal of the battery, as in Fig. *30*. Reconnect back to +C the lead now on —1½C, as shown in Fig. *30*, repeat each measurement indicated in Step 2, and record your results in Table *20C*. Make two additional measurements; first use a C bias of +3 volts by moving from —1½C to —3C the 7-inch lead which goes to —B, while leaving the hole *d* lead on +C. Next, use a C bias of +4.5 volts by moving from —3C to —4.5C the 7-inch lead which goes to —B, leaving the hole *d* lead still on +C.

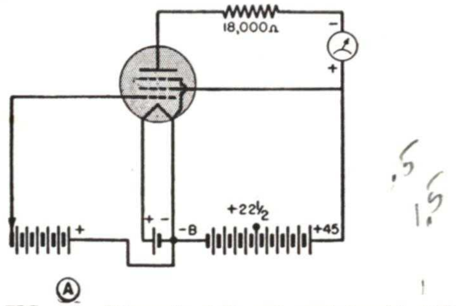
C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT IN MA.	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT IN MA.
-9			0	0
-7.5			0	0
-6			0	0
-4.5			0	0
-3			.1	.3
-1.5			.4	1.2
0			.9	2.7
+1.5			1.5	4.5
+3			2.2	6.6
+4.5			2.8	8.4

TABLE 20C. Record your results for Step 3 of Experiment 20 here. Remember that your own values are not expected to be the same as the NRI values given here for comparison purposes.

Step 4. To determine the effect of a plate load resistance upon the E_g-I_p characteristic curve of a pentode tube when operated with plate and screen grid voltages of 45 volts as indicated in the circuit of Fig. 31A, connect an 18,000-ohm resistor in series with the meter as indicated in Fig. *31B*. This is done by using ter-



GRAPH 20C. Plot on this graph the results you obtain in Step 3 of Experiment 20, and connect the points together to give a smooth curve. This will be the characteristic curve of your type 1C5GT tube when operated as a pentode with a plate voltage of 45, a screen grid voltage of 22.5, and no plate load.



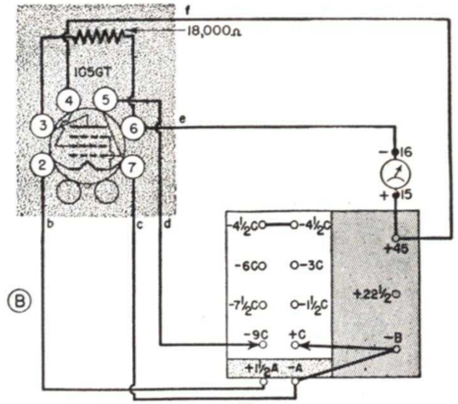


FIG. 31. Schematic *(A)* and semi-pictorial *(B)* diagrams for the circuit employed in Step 4 of Experiment 20.

minal *6* on the tube socket as an insulated support for one resistor lead. The actual connections under the socket are shown in Fig. *32;* observe that the wire coming through hole *e* has been moved from terminal *3* to terminal *6*, and the 18,000-ohm resistor has been connected between terminals *3* and *6* by means of temporary hook joints. Now disconnect the 910-ohm shunt resistor from meter terminals *15* and *16* so that the meter will read current values in ma. directly on scale I_M. Vary the C bias voltage value from —9 volts to +4.5 volts in 1.5-volt steps by following exactly the same procedure employed in Steps 2 and 3, and read the meter on scale I_M in each case. Record your results in Table *20D*, and plot the results on Graph *20D*.

Step 5. Prepare the parts for assembly of the NRI Tester by removing the vacuum tube from its socket, disconnecting all battery leads, then untying the black lace and removing *the entire group* of batteries all at once. Next, unsolder the leads on the meter terminals, unsolder all connections to the tube socket, then pull the leads out through the holes in the chassis. Straighten out the hooks at the ends of wires only when necessary to pull the wire through a hole, for you will usually have to form the hooks again when using the wire later. Separate the panel from the chassis by removing the three screws at the bottom of the panel, but leave the meter and jack strip mounted on the panel, and leave the tube socket on the chassis. Remove surplus solder from the meter terminal lugs, but do not remove these lugs. Remove surplus solder from the tube socket lugs; if difficulty is encountered in doing this, remove the socket temporarily

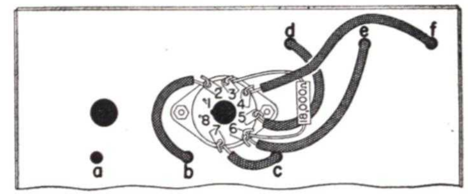


FIG. 32. Connections under the chassis for Step 4 of Experiment 20 should be as shown here. To make your circuit conform with this, move the plate lead (coming through hole *e)* from terminal 3 to terminal *6*, and connect an 18,000-ohm resistor between terminals *3* and *6*.

from the chassis so you can shake or tap off the surplus solder from each lug in turn without getting it into the prong holes.

Discussion: First of all, you should realize that the variations which occur normally in vacuum tubes and radio parts during manufacture make it practically impossible for you to secure exactly the same values and the same curves which we secured in the

NRI laboratory. Our values and our curves are shown merely for comparison purposes and to illustrate the procedure for plotting this type of data on graphs. You can be sure your work is entirely satisfactory if you secure merely the same general shape or slant of curves, but remember that even this shape or slant can vary considerably from that shown on a particular graph.

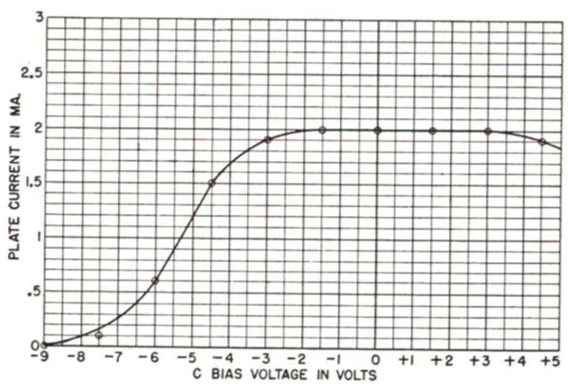
One thing which you should realize after performing this experiment is that the plate current does *not* always increase *uniformly* with changes in grid voltage. In other words, as the negative bias on the grid is reduced, the plate current will increase faster than it did when working with highly negative grid bias values, and the curve will tend to bend upward. Study your curves carefully, giving particular attention to the grid bias values at which the curves bend upward.

In Step 1 you take readings of plate current for various positive and negative C bias values while your type 1C5GT tube is connected as a triode without a plate load resistance. When you plot your values on Graph *20A* and connect the points together, you secure a curve which contains all of the information present in Table *20A*.

In addition, however, the curve which you draw can give you hundreds of other plate current values for C bias voltages in between the values at which you made measurements. Thus, if you wanted to find out what the plate current would be for a C bias voltage of —4 volts, you would simply trace upward from —4 on the horizontal scale until you came to the curve, then trace horizontally to the left from that point on the curve and read the value of plate current where you intersect the vertical scale of current.

It is this characteristic of a graph, wherein you can estimate in-between

C BIAS VOLTAGE IN VOLTS	YOUR PLATE CURRENT IN MA. (READ DIRECTLY ON SCALE I_M)	N.R.I. PLATE CURRENT IN MA. (READ DIRECTLY ON SCALE I_M)
-9		0
-7.5		.1
-6		.6
-4.5		1.5
-3		1.9
-1.5		2
0		2
+1.5		2
+3		2
+4.5		1.9



GRAPH 20D (above). Plot on this graph the results you obtain in Step 4 of Experiment 20, and connect the points together to give a smooth curve. This will be the characteristic curve of your type 1C5GT tube when operated as a pentode with a plate voltage of 45 volts, a screen grid voltage of 45 volts, and an 18,000-ohm plate load.

TABLE 20D (left). Record your results for Step 4 of Experiment 20 here. Remember that your own values are not expected to be the same as the NRI values given here for comparison purposes.

values with accuracy, which makes graphs so valuable in radio work.

When you connect your tube as a pentode in Step 2, with 45 volts on both the plate and screen grid, you would naturally expect to secure a slightly different characteristic curve than for triode operation. The curves in Graphs *20A* and *20B* resemble each other quite closely under the conditions of this experiment, with only minor differences in corresponding values, but these triode and pentode characteristics of the 1C5GT tube may differ considerably under other operating conditions.

Reducing the screen grid voltage on your pentode tube to 22.5 volts lessens the effectiveness of the screen grid, with the result that the E_g-I_p characteristics are altered considerably. The NRI curve in Graph *20C* differs quite appreciably from the previous two curves, as you can readily see by comparing them. The curve which you obtained for Step 3 should likewise differ from the previous curves in that it is shifted to the right on your graph with respect to values on the horizontal scale. The shape of the curve is still essentially the same as for Steps 1 and 2.

In Step 4, the 18,000-ohm resistor is placed in the plate circuit to limit plate current and duplicate more closely the actual operating conditions under which this tube would be used. The 910-ohm meter shunt is removed to improve the accuracy of readings, since the plate load resistor will limit the meter current to values considerably below the full-scale value of 3 ma. Now you secure a radically different characteristic curve, with a somewhat flat top. This curve is actually more useful to a radio man than the preceding three curves, for it more nearly represents actual conditions under which vacuum tubes are operated in radio circuits.

Instructions for Report Statement No. 20. To show the importance of graphs for giving operating values *in between* those actually measured for a vacuum tube, refer to your own characteristic curve for the type 1C5GT tube operating as a pentode with no plate load (this is Graph *20C* on page 50), and determine the plate current for a C bias of —1 volt. Do this by locating the —1 point on the horizontal scale, tracing vertically upward from this until you intersect your own curve, then tracing horizontally to the left from the intersection so you can read the plate current value in ma. on the vertical scale. Record the value in Report Statement No. 20 on the last page, and send in the page for grading.

IMPORTANT

These instructions may save you unnecessary trouble.

Send in your Report Statement for grading as soon as you finish Experiment 20.

DO NOT BUILD the NRI Tester until you have received a *passing grade* (A, B, or C) for this work. This will avoid the necessity of dismantling the tester in order to repeat any of the experiments for which you didn't get the right answers.

How To Assemble the NRI Tester

THE NRI Tester which you are now ready to build *(provided you have obtained a passing grade on Experiments 11-20)* is a complete and modern test meter designed to meet the requirements of professional radio servicemen for many years to come. This instrument, when assembled and calibrated according to the instructions given in this manual, will allow you to make many different measurements in radio circuits.

Actually, the NRI Tester is a combination vacuum tube voltmeter and multimeter which provides at least eighteen separate and distinct ranges. You will be able to measure a.c. voltages up to 550 volts in four ranges, d.c. voltages up to 450 volts in four ranges, direct current values up to 45 milliamperes in two ranges, resistance values up to 100 megohms in four ranges, and output measurements of radio receivers in four ranges.

Later, you will be provided with a headphone which can be plugged into the NRI Tester; with this combination you can listen to the quality and strength of audio signals anywhere in a radio receiver, thereby speeding up the location of defects which are causing distortion.

The sensitivity of the voltmeter ranges in the NRI Tester is quite high in comparison to that of other testers being used for service work. A sensitivity of 1,000 ohms-per-volt is considered satisfactory for most radio service work, but each d.c. voltage range in your NRI Tester has a sensitivity better than 20,000 ohms-per-volt. (Actually, on one range of your instrument, the sensitivity is well over 2,000,000 ohms-per-volt.) As a result, you can connect the NRI Tester to high-resistance circuits and make accurate voltage measurements without disturbing circuit conditions appreciably. Many of the measurements which are possible with the NRI Tester could not be made with ordinary meters.

The NRI Tester has been included in your practical demonstration course for several reasons. It gives you an opportunity to assemble a professional-quality test instrument yourself. It allows you to check circuit action and verify the various radio and electrical laws which are studied in your regular course. Finally, it gives you experience in using test instruments.

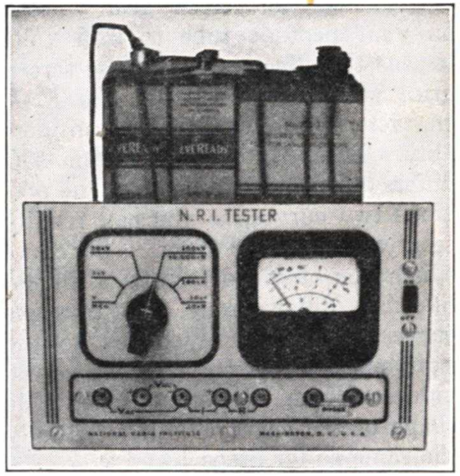


FIG. 33. Your NRI Tester should look like this after you have assembled it according to the simple step-by-step instructions in this manual, if you are using the specified Eveready batteries.

A completely assembled NRI Tester is shown in Fig. 33. As you can readily see the panel layout is remarkably simple considering the number of uses which the instrument has. At the extreme right on the panel is the switch which turns the instrument on and off. Next to the switch is the special four-scale meter on which all values are read. On the upper left half of the panel is the selector switch, which automatically connects the meter into the test circuit you desire for a particular measurement.

Below the meter and selector switch is the jack strip into which you plug the test leads for various measurements. The two jacks at the extreme right are for the phone which you will receive later; the shorting strip shown in this view is plugged into these two jacks whenever the phone is not used.

Step-by-step instructions for assembling the NRI Tester will now be given. Follow through these instructions slowly and carefully, doing the very best work of which you are capable, for you will want your instrument to show professional workmanship in each and every soldered joint. To make sure you do not miss any steps, place a check mark alongside each completed step as you go along.

Plan to devote a number of evenings to the assembly of this instrument, for the success of the remainder of your practical demonstration course depends entirely upon your assembling this instrument properly. Remember that we are ready to help you with advice whenever you encounter difficulties or have trouble in understanding the instructions.

The complete circuit diagram of the NRI Tester is given in Fig. 34 for reference purposes, and need not be studied at this time.

Instructions for using the NRI Tester will be given progressively in later manuals, as the need arises for the various types of measurements which it makes.

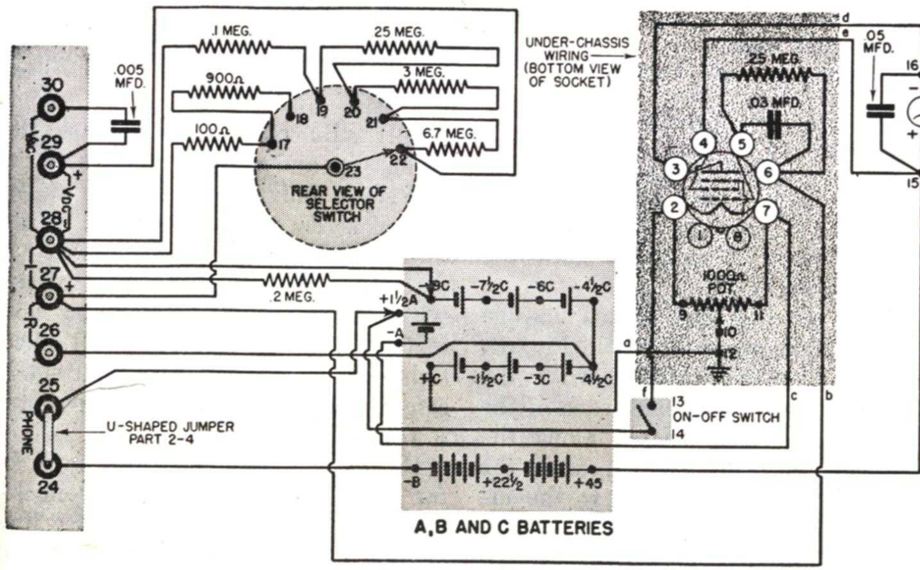


FIG. 34. Circuit diagram of the NRI Tester. This is presented here for reference and checking purposes: you will follow pictorial diagrams and photographs when assembling the unit, to minimize chances for errors. Note: The 6.7, .25, and .2-megohm resistors, and the 900-ohm resistor, shown above have been changed to 6.8, .24, and .22 megohms, and 910 ohms, as previously explained.

Mounting the Parts on the Front Panel

Step 1. To prepare for the preliminary mounting of parts on the panel, place before you the following parts:

Front panel (Part *2-2*) on which you have already mounted (in Experiment 11) the 0-3-ma. milliammeter with two soldering lugs (Parts *1-8A* and *1-8B*) and the 7-jack strip (Part *2-3*), with each terminal on these two parts identified by a number marked on the back of the panel in the manner shown in Fig. *6* in connection with Experiment 11 in this manual.

One ON-OFF power switch (Part 2-5).

One 6-position rotary selector switch (Part *2-6*).

One bar knob for the selector switch (Part *2-8*).

Two ¼-inch long binder-head machine screws (Part *2-18A*) and two hexagonal nuts (Part *2-18B*).

At this same time, arrange before you the following tools and materials, which will be needed during the assembly of the NRI Tester.

Long-nose pliers.

Side-cutting pliers.

Ordinary pliers.

Medium-size screwdriver.

Small screwdriver.

Twelve-inch ruler.

Soldering iron and holder (Parts *1-1*, *1-2*).

Rosin-core solder (Part *1-3*).

Red push-back hook-up wire (Part *2-17*).

One short length of yellow rubber and cotton-covered wire (Part *1-7F*).

Step 2. Mount the rotary selector switch (Part *2-6*) on the panel in the following manner:

While holding the switch in one hand in the manner shown in Fig. *35*, proceed to bend outward with the thumb of your other hand each of the six soldering lugs located along the outer edge of the switch, until the lugs are flat with relation to the insulating material at the back of the switch. Do not bend the single inside lug. *Do not use pliers for this bending;* the lugs can easily be pushed over with your thumb, if you start from one end of the row of lugs.

Remove the ⅜-inch nut from the shaft of the switch, and push the shaft through panel hole *t* (Fig. *36*) from the rear so that it has the position shown in Fig. *37*. Replace the nut on the shaft which now projects through the front of the panel, and tighten the nut first with your fingers and then with ordinary pliers as shown in Fig. *38*, while using one hand to hold the selector switch in the position shown in Fig. *37* (so that end terminals *17* and *22* on this switch are both the same distance from the top of the

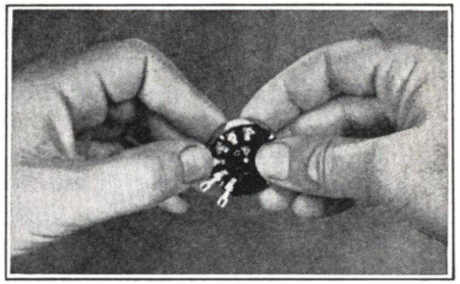


FIG. 35. Method of bending out the soldering lugs on the rotary selector switch (Part *2-6*). Press them outward with your thumb, one at a time, until all the outer lugs point outward like the spokes of a wheel. Do not bend the single center lug.

panel). Be careful not to let the pliers slip and scratch the panel.

With a small screwdriver, loosen the set screw which is located in the thick end of the bar knob (Part *2-8*), place this knob over the shaft of the selector switch with the set screw next to the flat portion of the shaft, then tighten this set screw with your small screwdriver while pressing the knob toward the panel.

Rotate the selector switch knob as far as it will go in a counter-clockwise direction, so that the white line on the pointer of the knob is on the panel line marked *V MEG.* If the pointer is not exactly on this line

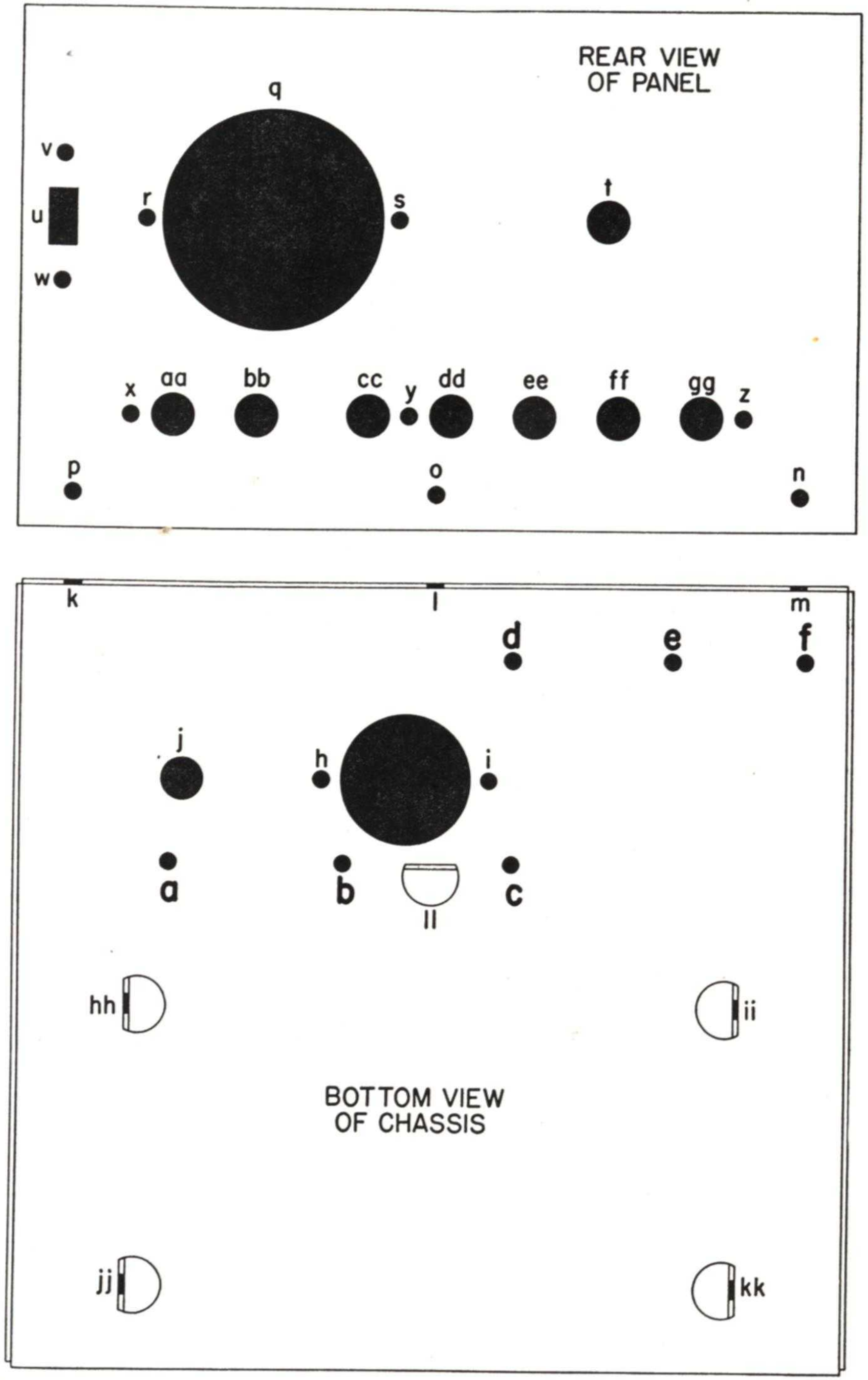


FIG. 36. Rear view of tester panel (above) and bottom view of chassis (below), with all holes identified by letters for convenience in referring to them. The only letters which are to be marked on your parts, however, are those identifying chassis holes, *a*, *b*, *c*, *d*, *e* and *f*. Use these diagrams as your guides for locating the other holes when mounting the parts.

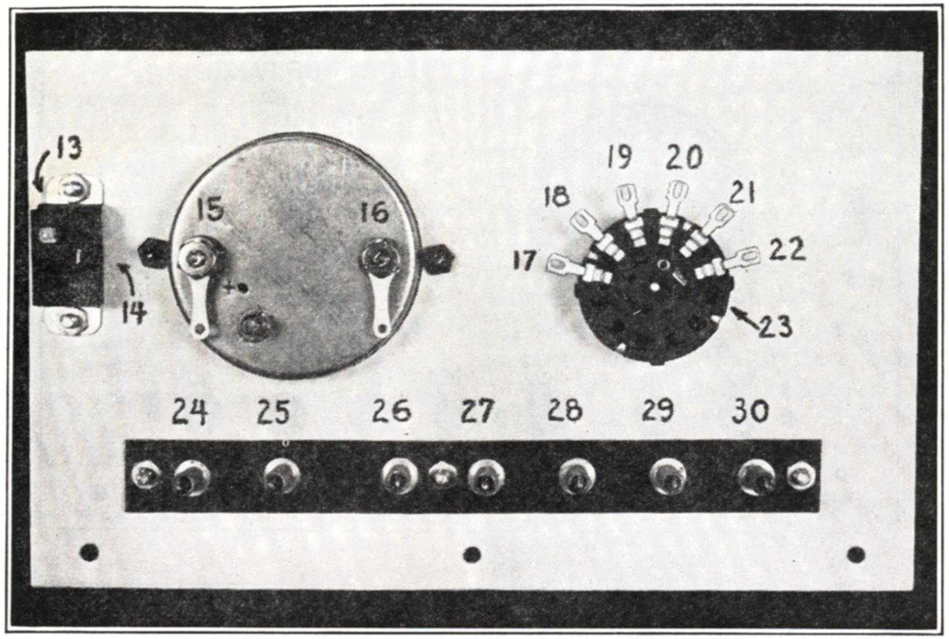


FIG. 37. The back of your tester panel should appear like this after you have mounted the selector switch and ON-OFF switch, as instructed in Steps 2 and 3. (The meter and jack strip were mounted as part of Experiment 11.) Number the various terminals on your own panel by marking them with crayon or pencil as shown in this view. Crayon markings can be wiped off with a cloth if errors in numbering are made.

when looking directly at it with your eyes on a level with the knob, grasp the back of the selector switch with your hand and rotate it firmly but slowly until the pointer is exactly on the line.

Step 3. Insert the ON-OFF power switch (Part *2-5*) *in rectangular panel hole u* (Fig. *36*) *from the back of the panel* in the position which places the colored dot next to the panel notation *OFF*. (Flip the switch back and forth to find the dot, for it is visible in only one position of the sliding black button.)

Attach the switch to the panel with two binder - head machine screws (Part *2-18A*) and two hexagonal nuts (Part *2-18B*), with the heads of the screws at the front of the panel. Tighten each screw with a screwdriver while holding its nut with ordinary pliers.

Step 4. Complete the numbering of the terminals at the back of the panel in the manner shown in Fig. *37*. Since the terminals for the meter and the jack strip were numbered in a previous experiment, this leaves only

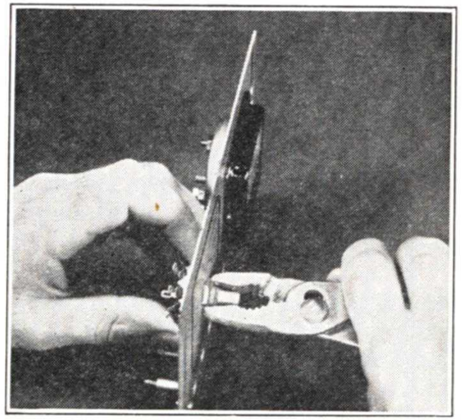


FIG. 38. Method of using ordinary pliers to tighten the nut on the rotary selector switch. Use the same technique for tightening the nut on the 1,000-ohm potentiometer.

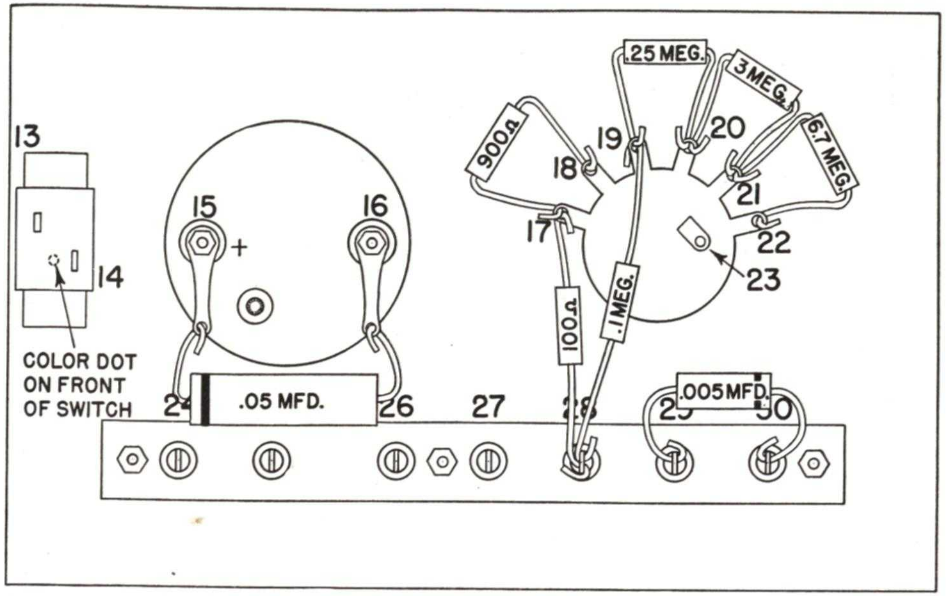


FIG. 39. Rear view of front panel, showing positions of all condensers and resistors. No soldered joints have been made yet. All hook joints should be closed when instructions for this are given in the text.

power switch terminals *13* and *14* and the selector switch terminals *17* to *23* to be numbered. Place these numbers carefully and neatly on the panel, as close as possible to each terminal, with your crayon pencil. Finally, place *on the top* of each jack the identifying number which you have previously placed on the back of the panel above the jack. This will simplify identification of the jacks while working with the panel facing you. Sharpen the crayon with your pocket knife when necessary.

Making Resistor and Condenser Connections on the Panel

Step 5. Locate and place before you on the table the following parts from Radio Kits 1RK and 2RK-1:

One .05-mfd. tubular paper condenser (Part *1-13*).

One .24-megohm (240,000 ohms) fixed resistor. (Part *1-14*).

One .1-megohm (100,000 ohms) fixed resistor (Part *1-15*).

One 6.8-megohm fixed resistor (Part *2-11*).

One 3-megohm fixed resistor (Part *2-12*).

One 910-ohm fixed resistor (Part *2-14*).

One 100-ohm fixed resistor (Part *2-15*).

One .005-mfd. tubular paper condenser (Part *2-16*).

One .22-megohm (220,000 ohms) fixed resistor (Part *2-22*).

Step 6. Connect the .05-mfd. condenser (Part *1-13*) *between meter terminals 15* and *16* by first shortening the leads with side-cutting pliers so that each lead is now 1 inch long. (Make marks on the leads with crayon after measuring with a ruler, and check each mark carefully before cutting so as not to get a lead too short.) Bend the leads with your fingers to the shapes shown in Fig. *39*, so that the condenser will fit under the meter and its wires will reach to the meter terminal lugs. Either condenser lead may be connected to the + terminal (*15*). Now bend an open hook in the end of each lead with long-nose pliers, and hook these leads through the holes in lugs *15* and *16* from behind. Close the hooks with long-nose pliers, but do not solder the joints until instructed to do so. In many cases, two or more wires must be placed on a lug prior to soldering.

Step 7. Connect the .005 mfd. condenser (Part *2-16*) *between jack terminals 29 and 30,* by first shortening each condenser lead until it is 1 inch long. Bend the leads with your fingers in the manner shown in Fig. *39.* Insert the end of one of the condenser leads into the hole in lug *30,* insert the end of the other condenser lead into the hole in lug *29* from the opposite direction, then bend the leads to form closed hooks, as shown in Fig. *39.*

Step 8. Connect the 910-ohm resistor (Part *2-14*) *between selector switch terminals 17 and 18,* by first shortening each lead so that it is ⅞ inch long. Bend the leads with your fingers to the approximate shapes shown in Fig. *39.* Bend an open hook in each lead with long-nose pliers. Insert the leads in terminal lugs *17* and *18* from behind, then close the hooks and squeeze them just enough so the resistor will support itself above the selector switch, in the position shown in Fig. *39.*

Step 9. Connect a 100-ohm resistor (Part *2-15*) *between selector switch terminal 17 and jack terminal 28,* by first shortening each resistor lead so it is ⅞ inch long. Bend an open hook in one lead with long-nose pliers, hook this lead into the hole in terminal *17* from behind, and close the hook. Now bend a partial hook (a simple right-angle bend) in the other lead so that you can push this lead into the hole in jack terminal *28,* as indicated in Fig. *39,* but do not close the hook yet.

Step 10. Connect the .1-megohm resistor (Part *1-15*) *between selector switch terminal 19 and jack terminal 28,* by first shortening each resistor lead until it is 1¼ inches long. Bend the leads to the shapes shown in *Fig. 39* so that the resistor will be held away from the switch housing, bend an open hook in one lead, hook this through the hole in lug *28* alongside the resistor lead now in that lug, but do not close this hook yet. Now make a right-angle bend in the other lead on a level with the hole in lug *19,* push the lead through this hole from the front, and bend the lead with long-nose pliers to form a closed hook on this lug.

Step 11. Connect the .24-megohm resistor (Part *1-14*) *between selector switch terminals 19 and 20,* by first shortening each lead of this resistor until it is ⅞ inch long. Bend the leads with your fingers to the shapes shown in Fig. *39.* Bend an open hook in the end of each resistor lead. Hook these leads through the holes in lugs *19* and *20* respectively from behind, and squeeze the hooks just enough with long-nose pliers so the resistor will support itself as shown in Fig. *39.*

Step 12. Connect the 3-megohm resistor (Part *2-12*) *between selector switch terminals 20 and 21,* by first shortening each resistor lead until it is ⅞ inch long. Bend the leads as in Fig. *39.* Bend an open hook in the end of each lead. Insert the leads through the holes in lugs *20* and *21* from behind, then squeeze each hook with long-nose pliers. You will now have two leads in lug *20.*

Step 13. Connect the 6.8-megohm resistor (Part *2-11*) *between selector switch terminals 21 and 22,* by first shortening each resistor lead until it is ⅞ inch long. Bend the leads as in Fig. *39.* Bend a hook in the end of

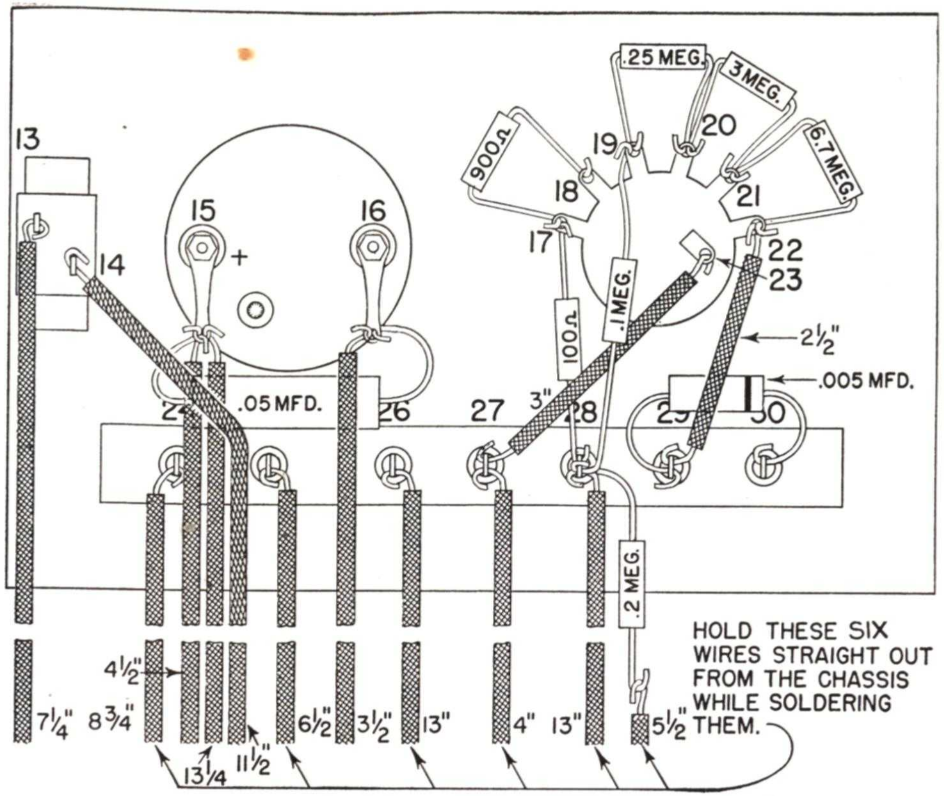


FIG. 40. Rear view of front panel after all leads and parts have been connected with permanent soldered hook joints. The length in inches to which you should cut each piece of hook-up wire is indicated alongside the wire. To save space in this manual and to simplify this diagram, the long leads are shown in shortened form below the panel. Each of the six long jack leads should be held at right angles to the panel while being soldered; these wires can then be bent to the right along the bottom of the panel so they will not interfere with your work. At this stage of the assembly, all joints should have *closed hooks* and be soldered exactly according to the instructions in the text.

each lead. Hook the leads through the holes in lugs *21* and *22* from behind, then squeeze each hook with long-nose pliers. The back of the panel of your NRI Tester should now appear exactly as shown in Fig. *39.*

Completing the Panel Connections

IMPORTANT: Lead lengths specified in these assembly instructions for the NRI Tester are based upon the dimensions of Eveready batteries. Cut your wires to these lengths even when using batteries having other dimensions, because you can easily shorten later any leads which are too long, or replace those few leads which might be too short.

Step 14. Heat your soldering iron now, for you will be using it soon. Cut a 4½-inch length of hook-up wire from the roll furnished you as Part *2-17,* push the insulation back from one end, bend a hook in this end, and insert this hook in the hole in meter lug *15* from behind, alongside the condenser lead already in this hole. Close the hook with pliers while holding the wire straight down along the panel as shown in Fig. *40.*

Now cut a 13¼-inch length of hook-up wire, push the insulation back from one end, bend a hook in that end, and insert this hook also in the hole in meter terminal lug *15.* Hold this wire straight down along the panel parallel to the other wire, then squeeze all three hooks which are in this lug. Solder this joint, using rosin-core solder. After the solder has hardened, push the insulation back toward the lug on each wire. Get the habit of pushing the insulation over exposed wire like this whenever using push-back wire.

Be sure to bend the lug away from the meter case so that there is at least a ¼-inch clearance between the joint and the case.

Step 15. Cut a 3½-inch length of hook-up wire, connect one end of it to meter lug *16* by means of a hook joint, squeeze the hook tight while holding the wire straight down along the panel as shown in Fig. *40,* then solder this joint. Finally, push the insulation on the wire up toward the joint if any wire is exposed below the joint, and bend the lug out ¼ inch.

Step 16. To connect together selector switch terminal 23 and jack terminal 27, cut a 3-inch length of hook-up wire, make a permanent hook joint with one end of this wire at terminal *23,* and solder this joint. Form a hook joint with the other end of the wire on terminal *27,* but do not solder this yet.

Step 17. Cut a 4-inch length of the stranded tinned rubber and cotton insulated wire (Part *1-7F,* left over from the first ten experiments), remove the insulation from both ends for a distance of about ¼ inch, then connect one end of it to jack terminal *27* with a permanent hook joint. Hold the wire perpendicular to the panel, and squeeze the hooks on both wires at this lug so the 4-inch wire will stand upright by itself when the panel is lying on the table, and solder the joint. (It is necessary to use the *1-7F* wire here because its rubber insulation prevents leakage.)

Step 18. Cut a 13-inch length of hook-up wire, form a hook in one end, and insert this hook in the hole in terminal *28* alongside the two hooks already there. Next, take the .22 megohm resistor (Part *2-22,* color-coded red, red and yellow on a brown body color), and connect a 5½-inch length of hook-up wire to the end of one resistor lead by means of a permanent soldered hook joint so as to lengthen this lead. Shorten the other resistor lead to a length of 1 inch, bend a hook in the end of this lead, and insert this hook also in the hole in terminal *28.* There should now be four leads in the hole in this terminal. Hold the 13-inch wire and the resistor straight out from the panel, squeeze each of the four hooks together with pliers, then solder this joint. Push the insulation on the wire toward the joint, then bend the 13-inch wire and the resistor lead to the right along the panel. (Take a glance at Fig. *42* now to see how the wires are bent to the right so they will be out of the way until needed again. Do not make sharp bends; keep each bend at least an inch away from its joint. Figure *40* merely shows the points to which the wires should be connected on the panel; it does *not* show the correct positions of those wires which extend below the panel and are left unconnected now.)

Step 19. Connect together terminals 22 and 29 by taking a 2½-inch length of hook-up wire, connecting one end to terminal *29* and connecting the other end to terminal *22* with permanent hook joints. Solder the joints at terminals *22* and *29.*

Step 20. Solder the joints at terminals 17, 18, 19, 20, 21 and 30 in turn, without placing any additional wires on these joints.

Step 21. Cut a 7¼-inch length of hook-up wire and solder one end of it

to power switch terminal 13 by means of a permanent hook joint, while holding the wire parallel to the panel as shown in Fig. *40.*

Step 22. Cut an 11½-inch length of hook-up wire and solder one end of it to power switch terminal *14* by means of a permanent hook joint while holding the wire parallel to the panel and bending it as shown in Fig. *40.*

Step 23. Cut a 6½-inch length of hook-up wire, attach it to jack terminal *25* by means of a permanent hook joint, hold the wire straight out from the panel, squeeze the hook together so the wire will stay there, then solder this joint on lug *25.* Push the insulation back, then bend the wire to the right.

Step 24. Cut an 8¾-inch length of hook-up wire, attach it to jack terminal *24* by means of a permanent hook joint, hold the wire straight out from the panel, squeeze the hook together so the wire will stay there, then solder the joint. Push the insulation back over the wire, then bend the wire to the right.

Step 25. Cut a 13-inch length of hook-up wire, attach one end of it to terminal *26* by means of a permanent hook joint, hold the wire straight out from the panel, squeeze the hook together so the wire will stay up, then solder the joint. Push the insulation back over the wire, then bend the wire to the right.

You have now completed all wiring which is to go on the panel of the NRI Tester.

Making Chassis Connections

Step 26. Set the completed front panel aside for the time being, and place before you the following parts from Radio Kits 1RK and 2RK-1.

Metal Chassis (Part *1-11*) on which you mounted (in Experiment 9) the octal-type tube socket (Part *1-10*).

1,000-ohm potentiometer (Part *2-7*).

One 13/16-inch long soldering lug (Part *1-8C*).

.24-megohm fixed resistor (Part *2-13*).

.03-mfd. tubular paper condenser (Part *1-12*).

45-inch length of black lace (Part *2-20*).

One grid cap clip (Part *2-21*).

Step 27. To mount the 1,000-ohm potentiometer (Part *2-7*) *on the chassis,* first remove the ⅜-inch hexagonal nut from the potentiometer shaft, in-

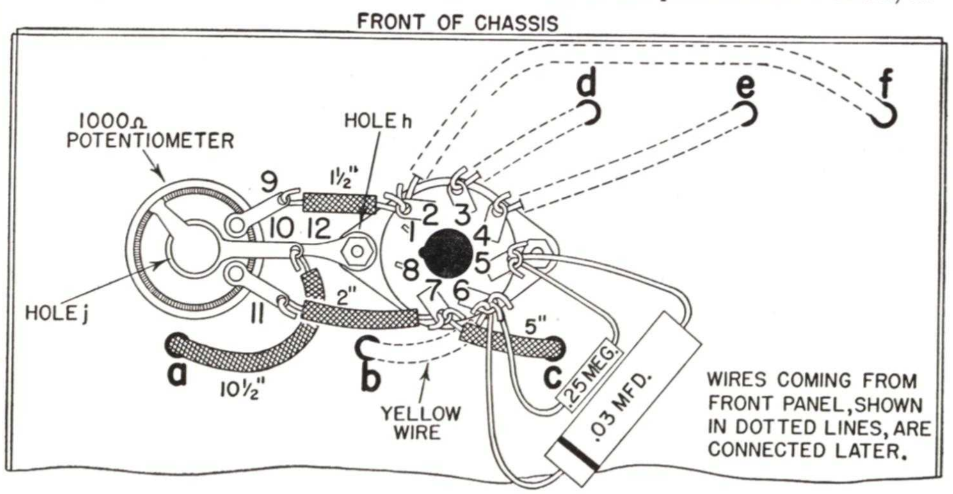


FIG. 41. Bottom view of chassis, showing preliminary assembly of leads and wires. After the chassis is bolted to the panel, four wires from the panel will be run through holes *b, d, e* and *f* and connected to terminals *6, 3, 4* and *2*, respectively, as indicated by the dotted lines.

sert the shaft through chassis hole *j* (Fig. *41*) from the bottom, and replace the nut on the shaft which now projects from the top of the chassis. Hold the potentiometer with one hand in the position shown in Fig. *41*, so that the middle soldering lug of the potentiometer is in line with the mounting bolts of the tube socket, and tighten the nut with ordinary pliers exactly as you tightened the nut on the selector switch shaft.

Step 28. Remove the nut from that tube socket mounting screw which is closest to the potentiometer (in hole *h*) without removing the screw, place on this screw a 13/16-inch long soldering lug (Part *1-8C*), and replace the nut. Tighten the nut partially with the fingers, bend the soldering lug up from the chassis at right angles, then line up the soldering lug with the middle lug of the potentiometer and tighten the nut finally with pliers and screwdriver.

Now take long-nose pliers and bend the outermost end of this lug back toward the chassis again so that it lies right over the center lug of the potentiometer, with the hole in lug *1-8C* coinciding with the slot in lug *10* of the potentiometer.

Mark the number *12* on the chassis alongside the lug which you have just bolted to the chassis, as shown in Fig. *41*. Identify the potentiometer terminal lugs by numbers *9*, *10* and *11* marked on the chassis near the lugs, as shown in Fig. *41*.

Step 29. Cut a $10\frac{1}{2}$-inch length of hook-up wire, push one end through chassis hole *a* from the top of the chassis, form an open hook in the end, insert this hook through the slot of lug *10* and the soldering hole in lug *12* (which now coincide), close the hook with long-nose pliers, then solder this joint so that lugs *10*, *12* and the $10\frac{1}{2}$-inch length of wire all form a single secure joint.

Step 30. Connect potentiometer terminal 11 to tube socket terminal 7 with a 2-inch length of hook-up wire, by forming permanent hook joints. Solder the joint at terminal 11, but do not solder the joint at *7* yet.

Step 31. Cut a 5-inch length of hook-up wire, push one end through hole *c* from the top of the chassis, and connect this end to tube socket terminal *7* by means of a permanent hook joint. Now solder the joint at terminal *7*.

Step 32. Connect potentiometer terminal 9 to tube socket terminal 2 with a $1\frac{1}{2}$-inch length of hook-up wire, using permanent hook joints. Solder terminal *9*, but do not solder terminal *2* yet.

Step 33. Connect the .24-megohm resistor (Part *2-13*) *between tube socket terminals 5 and 6,* by first shortening the resistor leads so that each is $\frac{3}{4}$-inch long. Bend the leads with your fingers to the shapes shown in Fig. *41*. Bend a hook in the end of each lead with long-nose pliers. Hook the leads through the holes in terminal lugs *5* and *6* from underneath, then close the hooks with long-nose pliers. Do not solder these joints yet.

Step 34. Connect the .03-mfd. condenser (Part *1-12*) *between tube socket terminals 5 and 6,* with the *outer foil* lead going to *6*, by first shortening the leads so that each is $1\frac{1}{4}$-inch long. Bend the leads as shown in Fig. *41* and form an open hook in the end of each with long-nose pliers. Hook the leads through the holes in terminals *5* and *6*, and close the hooks with long-nose pliers. Now solder the joints at terminal *5*, but do not solder terminal *6* yet. Adjust the leads now with your fingers and pliers so that the resistor and condenser are both self-supporting about $\frac{1}{8}$-inch away from the metal chassis.

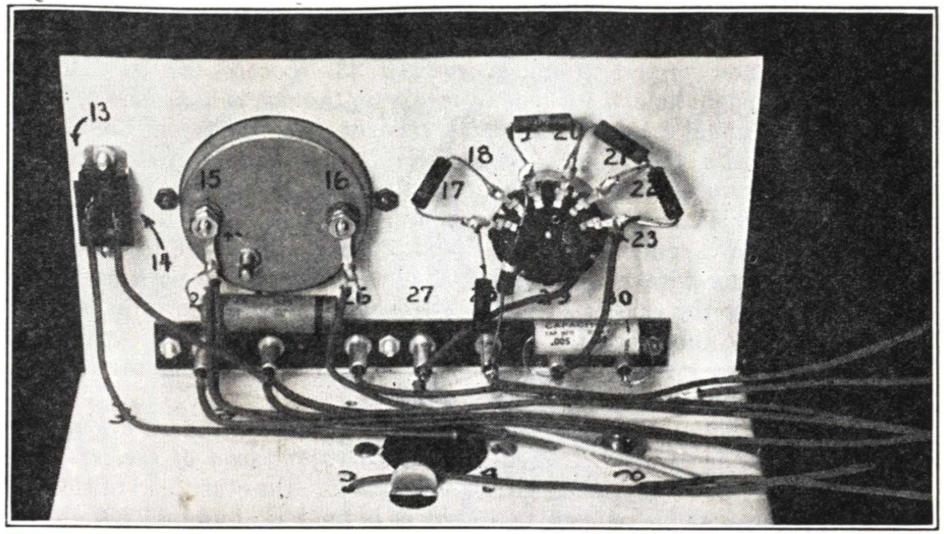


FIG. 42. Rear view of NRI Tester after the panel is fastened to the chassis. Note that the leads have been temporarily bent off the chassis to the right to permit placing the battery block on the chassis between the five tabs. The position of the *OUTSIDE FOIL* lead of the condenser connected between meter terminals *15* and *16* does not matter, since neither meter terminal is grounded.

You have now completed the wiring underneath the chassis as much as you can before final assembly. The bottom of the chassis should now appear as shown in Fig. *41*. Two wires will be projecting up through the top of the chassis, through holes *a* and *c* respectively.

Step 35. Fasten the panel to the chassis now with the three remaining binder-head machine screws (Part *1-9A*) *and three hexagonal nuts* (Part *1-9B* just as you did in Step 2 of Experiment 11, after first bending the projecting wires temporarily out of the way. Insert the screws one after another, placing a nut on each and tightening loosely with the fingers while the chassis is in the position shown in Fig. *5*. Now align the panel neatly with respect to the chassis, and tighten the screws permanently with screwdriver and ordinary pliers. At this stage in the assembly process, your NRI Tester should appear as shown in Fig. *42*.

Step 36. Locate the panel wire which you connected to terminal 13 of the power switch, and push this wire through chassis hole f (directly under terminal *13*). Connect to socket terminal *2* with a permanent hook joint the wire which projects underneath the chassis through hole *f*. Solder terminal *2* now (there should be two wires on this terminal).

Step 37. Locate the $4\frac{1}{2}$-inch wire which is soldered to meter terminal 15, and push the free end of this wire through chassis hole e, which is almost directly under this meter terminal. Underneath the chassis, connect to tube socket terminal *4* by means of a permanent hook joint the wire which is now projecting through hole *e*, and solder this connection to terminal *4*.

Step 38. Locate the $3\frac{1}{2}$-inch wire which is connected to meter terminal 16, push it through chassis hole d (directly under this meter terminal), then turn the chassis over and connect to tube socket terminal *3* by means of a permanent hook joint the wire which is now projecting under the chassis through hole *d*. Solder this joint on terminal *3* now.

Step 39. Locate the 4-inch wire 1-7F which is connected to jack terminal 27, and push it through hole b. When you have pulled the wire through, shape the wire neatly with your fingers above the chassis so that it goes around the tube socket. Now turn the chassis over and connect to tube socket terminal *6*, by means of a permanent hook joint, the wire *1-7F* which projects underneath the chassis through hole *b*. Close the hook with long-nose pliers, then solder terminal *6*.

Step 40. Locate the U-shaped shorting piece made from heavy wire (Part *2-4*), *and push this piece all the way into the two jacks marked PHONE at the front of the panel.* This piece can be seen in the view of the completed NRI Tester (Fig *33*). Do not remove this piece until you receive instructions for doing so in connection with the use of a headphone unit.

Mounting the Batteries

Step 41. Replace the group of batteries on top of the chassis exactly as shown in Fig. *19C*, and tie them in position with the black lace just as you did before. Be sure that the terminal identification card is in position and the two —4½C terminals are connected together *exactly as shown in Fig. 19D*. You can readily thread the black lace under the card when tying down the batteries.

Step 42. Locate the wire which projects through hole c and push the insulation back from its end about half an inch. Bend this end downward and insert its end in the spring clip of the —A terminal, then form the wire neatly with your fingers so it has the position shown in Fig. *43*.

Step 43. Locate the wire which comes up through chassis hole a, bring it straight up to the top of the C batteries, bend it sharply toward the +C terminal along the top of the batteries, then push back the insulation and connect this wire to the +C terminal. Adjust the position of the wire now so it is as shown in Fig. *43*. This position keeps the wire at least a quarter inch away from the +1½A terminal.

Step 44. Locate the wire which is attached to one lead of the .22-megohm resistor (the other lead of this resistor is on jack terminal *28*), bring this wire diagonally upward to the —9C terminal, connect the wire to —9C with a *closed* hook, and tighten the knurled nut on this terminal. Now straighten out any bends in the wire or the resistor leads, so this lead has the position shown in Fig. *43*.

NOTE: Whenever you connect a wire to a screw terminal, always bend the hook in the wire in a clockwise direction. Since a nut is tightened by turning it in a clockwise direction also, tightening of the nut will tend to close the hook in the wire rather than open it. Hooks which are bent in the opposite direction (counter-clockwise) will sometimes spread apart and fall off when the nut is tightened, hence this is to be avoided.

Step 45. Locate the wire which comes directly from jack terminal 28, and solder the grid clip (Part *2-21*) to the end of this lead with a permanent soldered hook joint, as shown at the upper right in Fig. *43*. This clip will be called the *calibrating clip*. Now run this lead down along the chassis from jack *28* to the left front corner of the A battery (near chassis hole *a*), then bring the wire straight

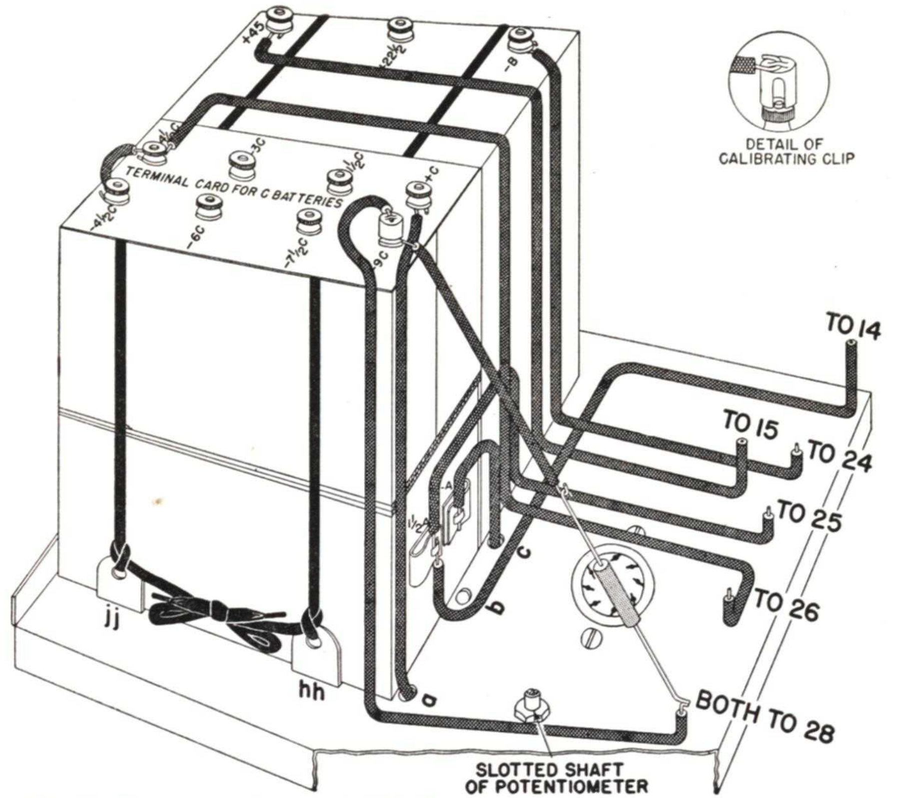


FIG. 43. Battery connections for the NRI Tester when using the specified Eveready batteries.
WARNING: DO NOT LET METER TERMINAL *15* OR THE +45 TERMINAL OF THE BATTERY COME IN CONTACT WITH THE CHASSIS OR WITH ANY OTHER BATTERY TERMINAL, BECAUSE AN ACCIDENTAL CONNECTION OF THIS NATURE MAY BURN OUT THE TUBE OR THE POTENTIOMETER, OR BOTH.

up along the front left corner of the battery group. At the top, form a loop in the rest of the wire as shown in Fig. *43*, and push the calibrating clip over the knurled nut on terminal —9C.

If the calibrating clip fits loosely, squeeze it together a bit with pliers or your fingers to get a snug fit. The extra loop of wire is required because the calibrating clip will at times be moved to terminals —7½C, —6C or —4½C.

Step 46. Locate the wire which comes from jack terminal 26, press it down along the chassis up to the B battery, bring it straight up the side of the B battery, bend it over the top edge, run straight back along the top almost to the back corner, then make a right-angle bend toward the —4½C terminal, and connect the wire to the right-hand —4½C terminal exactly as shown in Fig. *43*. Tighten the knurled nuts on terminals —6C and —7½C at this time.

Step 47. Locate the wire which comes from terminal 25, bring this wire straight back along the chassis, straight up along the side of the B battery to a point about 2 inches above the chassis, bend at right angles to the left, then bend downward at a point directly over the +1½A terminal, and connect the wire to the +1½A terminal.

Step 48. Locate the wire which comes from power switch terminal 14 and bring the wire straight down to the chassis, back along the chassis to the B battery, along the chassis just in front of the batteries, then up to the +1½A terminal, and connect to this terminal.

Step 49. Locate the 13¼-inch wire which comes from meter terminal 15, bring it straight down from this meter terminal to the chassis, make a right-angle bend there and bring it straight back along the chassis to the B battery, then make another right-angle bend and bring it up along the side of the B battery. Bend the wire at right angles over the front top edge of the battery block, run it straight back along the top of the B battery, push back the insulation, connect the wire to the +45 terminal, then adjust its position as shown in Fig. *43*.

Step 50. Locate the wire which comes from jack terminal 24, bring it back along the chassis to the B battery, then make a right-angle bend and bring it up along the side of the battery. At the top, bend the wire over and connect it to the —B terminal as shown in Fig. *43*.

You have now completed the battery connections for the NRI Tester. Go over all connections and push the insulation toward the joints whenever possible, to cover as much exposed wire as you can and thus minimize chances for accidental short circuits. When using the specified Eveready batteries, your completed tester should now appear essentially as shown in Fig. *44*.

Checking the Connections

Step 51. Having completed the assembly and wiring of the NRI Tester, you are now ready to check the accuracy and completeness of your connections by means of the complete circuit diagram given in Fig. *34*. This checking procedure is an important part of any radio assembly job, so go through it slowly and carefully. *Place a check mark (√) in the space provided for this purpose after each step in the following checking procedure,* when you are certain that the connections called for in that step are correct.

Tube socket terminal *2* should have two leads, one going to potentiometer terminal *9* and the other going through chassis hole *f* to *ON-OFF* switch terminal *13*. ☐

Tube socket terminal *3* should have one lead, going through chassis hole *d* to meter terminal *16*. ☐

Tube socket terminal *4* should have one lead, going through chassis hole *e* to meter terminal *15*. ☐

Tube socket terminal *5* should have two leads, one from a .03-mfd. condenser and **the other from a .24-megohm resistor.** ☐

Tube socket terminal *6* should have three leads, one from a .03-mfd. condenser, **another from a .24-megohm resistor, and a** yellow lead going through chassis hole *b* to jack terminal *27*. ☐

Tube socket terminal *7* should have two leads, one going to potentiometer terminal *11*, and the other going through chassis hole *c* to the —A terminal of the battery block. ☐

Terminal *10*, the middle lug of the potentiometer, should be grounded to soldering lug *12* which is bolted to the chassis, and should have a lead going through hole *a* to the +C terminal on the battery. ☐

Terminal *14* on the *ON-OFF* switch should have one lead, going to the +1½A battery terminal. ☐

Terminal *15* on the meter should have three leads, one from a .05-mfd. condenser, one going to +45, and one going through chassis hole *e* to tube socket terminal *4*. ☐

Terminal *16* on the meter should have two leads, one from a .05-mfd. condenser and the other going through chassis hole *d* to tube socket terminal *3*. ☐

Selector switch terminal *17* should have two leads, one from a 100-ohm resistor **and the other from a 910-ohm resistor.** ☐

Terminal *18* should have one lead, from **a 910-ohm resistor.** ☐

Terminal *19* should have two leads, one from a .1-megohm resistor and the other **from a .24-megohm resistor.** ☐

Terminal *20* should have two leads, one **from a .24-megohm resistor and the other** from a 3-megohm resistor.

Terminal *21* should have two leads, one from a 3-megohm resistor and the other **from a 6.8-megohm resistor.** ☐

Terminal *22* should have two leads, one **from a 6.8-megohm resistor and the other** going to jack terminal *29*. ☐

Terminal *23*, the central terminal on the selector switch, should have one lead, going to jack *27*. ☐

Jack terminal *24* should have one lead, going to —B.

Jack terminal *25* should have one lead, going to +1½A. ☐

Terminal *26* should have one lead, going to —4½C.

Terminal *27* should have two leads, one going to selector switch terminal *23* and the other (a yellow lead) going through chassis hole *b* to tube socket terminal *6*. ☐

Terminal *28* should have four leads, one **from a .1-megohm resistor, one from a .22-**megohm resistor, one from a 100-ohm resistor, and one going to the calibrating clip which should now be on terminal —9C. ☐

Terminal *29* should have two leads, one from a .005-mfd. condenser and the other going to selector switch terminal *22*. ☐

Terminal *30* should have one lead, from a .005-mfd. condenser. ☐

The U-shaped shorting piece should be in the phone jacks (connecting together jack terminals *24* and *25*.) ☐

Calibrating the NRI Tester

Step 52. Place the assembled NRI Tester on the table in front of you, with the panel facing you. Set the selector switch to the *100 × V* line on the panel (the selector switch is at this position in Fig. *33*.) Set the power switch to the *OFF* position by pushing the black slide *down*.

Insert the vacuum tube in its socket on the tester chassis; do this by placing the aligning key of the tube gently in the corresponding hole in the socket, then rotating the tube until you can feel that the projecting pin on one side of this key is in the corresponding groove in the center hole of the socket. Now push the tube firmly into the socket until the tube base is resting on top of the socket. There should be no movement of the meter pointer yet.

Step 53. Turn on the tester switch by pushing the button on this switch upward toward the position marked *ON*. The colored dot under the button of this switch will now be visible. You will probably note a small movement of the meter pointer to the right when this is done.

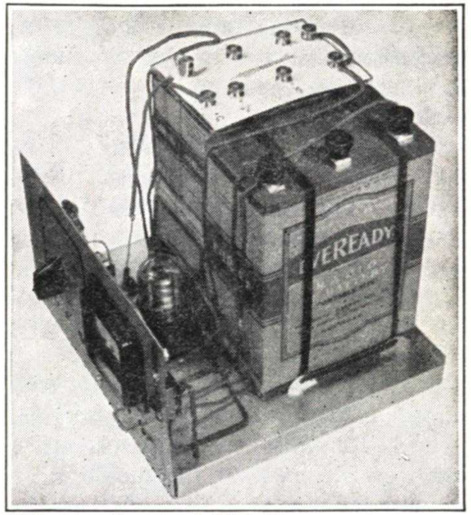


FIG. 44. Completed NRI Tester, as it appears when the specified Eveready batteries are used.

CAUTION: If you are interrupted while calibrating the NRI Tester, be sure to push this switch *OFF* in order to conserve the battery life. Energy is drawn from the batteries whenever this switch is *ON*.

Step 54. With the tester still turned on, adjust the zero-correcting knob at the back of the meter until the pointer is at *0* on the *DC* scale (the scale directly above scale I_M), while tapping the top of the meter lightly with a finger to overcome bearing friction. *DON'T USE PLIERS* to turn the zero-correcting knob, because the pliers may touch meter terminal *15* and burn out both the tube and potentiometer.

Step 55. Remove the calibrating clip from battery terminal —9C, and place it on battery terminal —7½C (this calibrating clip is on the lead which goes to jack terminal *28*). Now adjust the 1,000-ohm potentiometer on the chassis (Part *2-7*) with a screwdriver while tapping the top of the meter lightly with a finger, until the meter pointer is at 1.5 on the *DC* scale.

Important: ALWAYS USE THE *DC* SCALE DURING CALIBRATION. The I_M scale is needed only when the meter is used by itself as it was in previous experiments; this I_M scale is no longer needed now that the meter is in the *NRI* Tester circuit.

Step 56. Remove the clip from terminal —7½C and place it back on —9C. Readjust the zero-correcting knob at the back of the meter until the pointer is at *0* on the *DC* scale.

Step 57. Place the clip on terminal —7½C, and readjust the potentiometer until the meter pointer is at *1.5* on the *DC* scale.

Step 58. Continue this sequence of adjustments until you attain the desired condition whereby the meter pointer is at *0* when the clip is on terminal *—9C*, and the meter pointer is at *1.5* on the *DC* scale when the clip is on terminal *—7½C*. (Three repetitions of this procedure should give an accurate calibration.) This completes the calibration procedure, so your NRI Tester is now ready for use.

Step 59. Place the clip permanently on the —9C terminal of the battery. turn off your completed and calibrated NRI Tester by pushing the switch button downward to the position marked *OFF,* then place the tester aside until you receive further instructions for its use in Manual 3RK.

The greatest hazard to battery life lies in leaving the tester turned on overnight or for several hours at a time when not using it. Whenever you leave the tester, *make sure* the switch is *OFF*.

Completely remove both test leads from the input jacks whenever you finish with the tester to avoid accidentally exhausting the C battery.

The meter pointer may drop *below zero* when you turn the tester off, but this action is unimportant and can be neglected. The pointer will move up to zero again when you turn on the tester and tap the panel.

Supplementary Calibrating Instructions

Variations in tube characteristics and battery voltages may make it impossible for you to calibrate your NRI Tester as described in Steps 54-58. If your tester has been assembled correctly and contains no defective parts, the following information and instructions should help you secure the desired condition described in Step 58.

High-Emission Tube. Although the manufacture of vacuum tubes is a highly developed art, it is extremely difficult to make exactly identical tubes by mass production methods. The tubes which are made for the NRI Tester are carefully processed and selected, but can still vary considerably in their characteristics. As a result, you may find that the tube which is sent you for use in your NRI Tester will not permit the normal adjustment specified in Step *58*. To be more specific, the tube which you receive may have higher cathode emission than normal, with the result that you will be unable to bring the meter reading *down to 1.5* on the *DC* scale by adjusting the potentiometer while the calibrating clip is on the *—7½C terminal.* This condition will occur only with a new battery, and is remedied by lowering the plate voltage on the tube temporarily in the manner described in the next step.

Step 60. To reduce the effective plate voltage by 1½ volts, connect the cathode lead to —A instead of to *+1½A*. To do this, remove from the *+1½A* terminal the lead which goes to jack terminal *25*, and connect this lead to the —A terminal, so that there are now two leads on —A and only one lead on *+1½A.* After changing the wiring as instructed in this step, repeat the calibrating procedure set forth in Steps 55 to 59.

Remember that when the B battery ages sufficiently, it will drop in voltage and make it necessary for you to restore the original connection.

Run-Down B Battery. As the B battery ages and its voltage drops, you eventually reach the condition in which the plate voltage on the tube is too low to permit a calibration according to Step 58. In other words, you will find it impossible to bring the meter reading *up to 1.5* on the *DC* scale by adjusting the potentiometer. As a rule, this condition will not occur for several months if you follow the instructions given in later manuals for the use of the NRI Tester and turn on the tester only while you are actually making measurements. When the condition occurs, you can still use your batteries for a considerable period of time by lowering the C bias 1½ volts in the simple manner described in the next step (Step 61).

New Tube. Occasionally, a new tube will give the same condition as a partly run-down B battery, wherein it is impossible to bring the meter reading *up to 1.5* during calibration. The procedure in Step 61 will take care of this also.

Step 61. To reduce the effective negative C bias voltage 1½ volts, locate the wire which comes up through chassis hole *a,* and move it from the +C terminal to the —1½C terminal. The calibrating procedure set forth in Steps 55 to 59 should now be repeated.

Of course, none of the above procedures will correct for defective parts, incorrect connections, or incomplete soldering. If you still fail to obtain a satisfactory calibration, locate in the list below the type of trouble you have encountered and then read the information, and carry out the instructions given concerning it.

1. No reading, Step 55. No reading with the switch ON, even with the calibrating wire on —7½C, may be due to a defective ON-OFF switch, poor connections at the A or B battery terminals, a defective tube (open filament), or a defective (open) meter. Make sure the nuts on the ON-OFF switch do not restrict the movement of the sliding portion of the switch, check the tester thoroughly for loose connections and incorrect wiring, and then have a reliable radio dealer test the tube and check the meter for continuity.

2. Full-Scale Deflection for Step 53. A full-scale deflection of the meter pointer as soon as the tester is turned on is usually due to insufficient grid bias. Carefully inspect your C batteries to make sure they are interconnected *exactly* as instructed on pages *28-31*, and illustrated in Fig. *19*. You should also check to see that all connections to the C batteries are secure. Have the C batteries checked by a reliable radio dealer. If they check O.K., look for an open or a ground in the grid circuit.

The full-scale deflection could also be caused by a defective tube, so have it checked carefully in a tube tester.

Note. If you have to replace the tube, don't use anything but a type 1C5 (GT or GT/G) as this is the only tube that will work satisfactorily in the NRI Tester. *The 1A5 and 1Q5 tubes so often used as substitutes for the 1C5 in radio receivers will not work in your NRI Tester.*

3. *Full-Scale Deflection for Step 50.* A full-scale deflection as soon as the B battery is connected into the circuit, and before the tube is plugged into its socket, indicates a ground in that portion of the plate circuit between meter terminal *16* and plate terminal *3* of the tube socket. *Disconnect the B battery immediately* or it will quickly become exhausted, and the meter may burn out. Check the bottom of the tube socket, and remove all excess solder. Be sure that the insulation on the wire going up to meter terminal *16* through hole *d* keeps this plate lead from touching the chassis. If no ground is apparent, the meter itself is probably grounded. Write to us and we will tell you how to clear up this type of trouble.

4. *Meter Won't Come Down to 1.5.* This type of trouble is usually due to insufficient bias. If you cannot correct the trouble as described in Supplementary Calibration Step 60, have the C battery voltage checked. If one of the C batteries is low, replace it, and make sure that Jacks *26* and *28* are not grounded in any way.

5. *Meter Won't Go Up to 1.5.* This type of trouble can be caused by a low A battery as well as a low B battery and defective tube. Therefore, if Supplementary Calibration Step 61 and a new tube fail to bring the meter pointer up to 1.5, have the A battery checked. Replace it if the voltage is less than 1.2 volts under a 100-milliampere load.

Step-by-step operating instructions are given in later Manuals.

Important

Do not discard any of the parts supplied to you in NRI radio kits until you have completed your Course. All the parts left over after assembling the NRI Tester will be used in later experiments.

If you write to NRI regarding the complete tester, please refer to it as the *NRI Tester for Experiments*.