INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 41 TO 50

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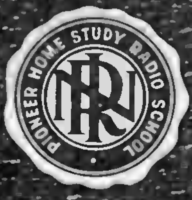

PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

N.R.I. AGAIN PIONEERS

Among the most baffling of all measurements are those involving r.f. voltages. For this reason, the training of technicians has in the past been generally limited to d.c., a.c. and possibly a.f. measurements. This explains why radio men today look upon an r.f. measurement as something mysterious which gives unexplainable results unless made in a research laboratory with special instruments costing hundreds of dollars.

Actually, however, most of the r.f. measurements required in practical radio work can be made easily, with inexpensive test instruments, if a few basic rules are understood and followed.

A series of remarkably simple and effective r.f. measuring techniques for the N.R.I. Tester has been developed in the N.R.I. laboratory. We are proud to be among the first in this country to offer a thoroughly practical training in r.f. measuring techniques.

The experiments in this manual and the next manual have been planned to give valuable practical experience in making r.f. measurements successfully and with confidence. Perform each experiment slowly and carefully so you will understand its full significance, and use the Technical Consultation Service whenever questions arise.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1950 Edition

A LESSON TEXT 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 Experiments 41 to 50

Introduction

YOU are now ready to begin work with audio and radio frequency circuits. You will set up typical practical circuits and make measurements of r.f. and a.f. signals in these circuits with your N.R.I. Tester. You will learn techniques which eliminate many of the difficulties usually encountered when making r.f. measurements, and will acquire a practical attitude toward r.f. signals which will be of great value in your work as a Radiotrician.

First of all, you will assemble an audio frequency oscillator and carry out experiments which demonstrate how it operates and how its frequency can be varied.

Next, you will assemble a resistance-capacitance coupled audio amplifier stage and analyze its characteristics. You will demonstrate the highly practical fact that while the theoretical maximum amplification of a stage depends upon the amplification factor of the tube, the actual over-all gain of the stage is less and depends upon the nature of the load circuit.

You will build an r.f. oscillator and an r.f. amplifier stage, and learn how resonant circuits can be used to increase the gain of an r.f. amplifier stage. The r.f. oscillator will serve as your signal source for r.f. amplifier experiments. You will learn how loading affects the gain of the stage.

Finally, you will assemble both an r.f. oscillator and an a.f. oscillator, and interconnect them so that the a.f. signal modulates the r.f. oscillator. Thus, you produce a modulated r.f. signal which simulates, for experimental purposes, the signal produced by a broadcasting station or by modern radio servicing instruments. You will leave this modulated r.f. oscillator set up for use in connection with later experiments.

Contents of this Radio Kit

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

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

Information on Type 6F8G Tube

The type 6F8G tube which is supplied to you in this Radio Kit is really two vacuum tubes mounted in a single glass envelope. The filament is the only part which is common to both sections of the tube; since this is a heater-type tube with two independent cathodes, this filament is present merely for heating purposes, and need not be connected to the r.f. or a.f. circuit in which the tube is employed. According to the tube manufacturer, the type 6F8G tube is actually two type 6J5G tubes in a

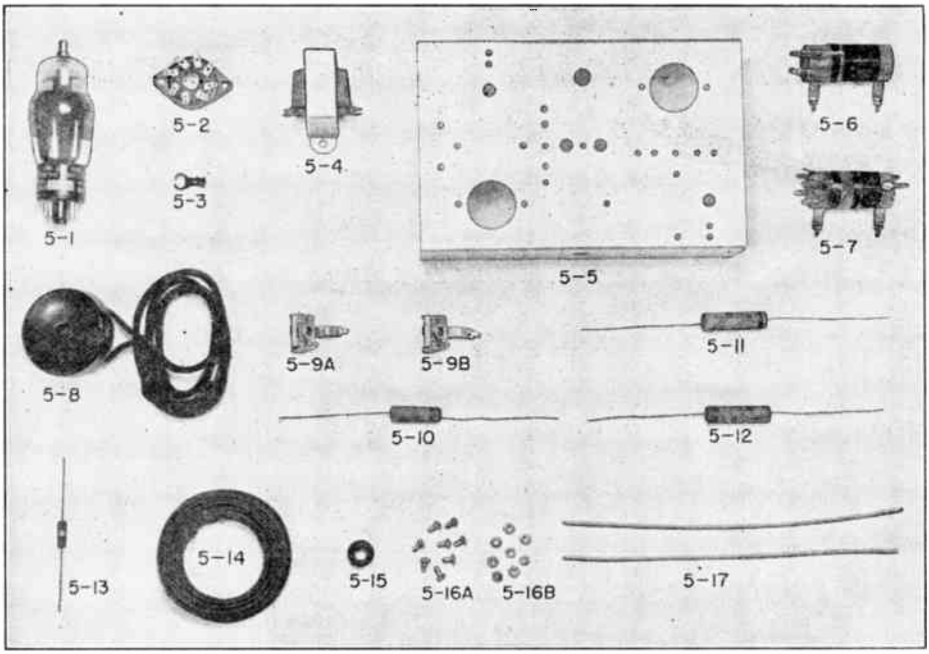


FIG. 1. The parts included in this Radio Kit are pictured above, and identified in the list below. Some resistors may have a better tolerance (lower percentage tolerance) than that indicated here.

Part No.	*Description*
5-1	One type 6F8G double-triode vacuum tube.
5-2	One octal-type tube socket with 8 terminal lugs.
5-3	One grid clip for octal-type tubes.
5-4	One audio transformer with 2½-to-1 turns ratio.
5-5	One cadmium-plated steel chassis bent to shape, with all holes already punched for parts used in 5RK.
5-6	One standard broadcast band antenna coil, with two mounting screws, four nuts and two wooden spacers.
5-7	One three-winding signal generator coil with two mounting screws, four nuts and two wooden spacers.
5-8	One 1,000-ohm headphone unit.
5-9A	One 370-mmfd. trimmer condenser with mounting bracket.
5-9B	One 370-mmfd. trimmer condenser with mounting bracket (same as Part *5-9A*).
5-10	One .001-mfd., 400-volt paper condenser.
5-11	One .01-mfd., 400-volt paper condenser.
5-12	One .05-mfd., 400-volt paper condenser.
5-13	One 100,000-ohm (.1-megohm), ½-watt resistor with 10% tolerance (color-coded brown, black, yellow, silver).
5-14	One 25-foot roll of push-back hook-up wire with red insulation.
5-15	One small rubber grommet.
5-16A	Eight ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
5-16B	Eight cadmium-plated hexagonal nuts for 6-32 screws.
5-17	Two 8-inch lengths of No. 20 stranded tinned rubber and cotton insulated wire.
5-18	One 1000-ohm, ½-watt resistor of 10% tolerance. (Not shown above.)

The following parts which should be left over from previous radio kits will be needed in the next ten experiments.

1-16	One 18,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, gray, orange, silver).
3-2A & B	Two .25-mfd., 400-volt paper condensers.
3-4	One 220-ohm, 1-watt resistor of 10% tolerance (color-coded red, red, brown, silver).
3-5A, B & C	Three 1,000-ohm, ½-watt resistors with 10% tolerance (color-coded brown, black, red, silver).
3-6A, B, C & D	Four 40,000-ohm, 3-watt resistors with 20% tolerance (color-coded yellow, black, orange).
3-8	One 1,000-ohm wire-wound potentiometer.
3-12	One 6-lug terminal strip, with four of the lugs insulated.
4-21	One 10-megohm, ½-watt resistor with 10% tolerance (color-coded brown, black, blue, silver)
	One N.R.I. assembled Tester (Kit 2RK) and power pack (Kit 4RK).

single envelope; if you examine the internal structure of your tube carefully, you may be able to see the two sets of tube elements.

The schematic symbol for a type 6F8G tube is shown in Fig. *2*. This diagram also identifies the terminals of this tube when looking at the bottom of the socket or when looking at the bottom of the tube base.

The glass inside your type 6F8G tube may have a black or silvery metallic deposit; this is the tube shield, and is connected internally to prong *1* on the tube base. The solid black dot at terminal *1* in the schematic symbol in Fig. *2* is a common means of indicating that there is an internal shield connection to this terminal.

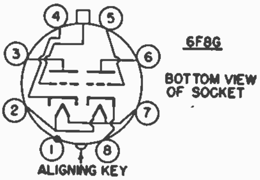


FIG. 2. Combination schematic and socket connection diagram for the type 6F8G double-triode tube supplied to you in this Radio Kit.

The filament (heater) terminals are *2* and *7*. Terminals *8*, *5* and *6* are the cathode, control grid and plate respectively of one triode section. Terminals *4*, the top cap and *3* are the cathode, control grid and plate terminals of the other triode section. Thus, the top cap of the tube goes to the control grid of one triode section.

Since this is an octal tube, the aligning key is in its standard position between terminals *1* and *8*. Any terminal on the tube socket can be readily located and indentified by reference to the position of this aligning key.

Your type 6F8G tube has a rated filament voltage of 6.3 volts, and draws .6 ampere of filament current when this filament voltage is applied. The tube will work satisfactorily, however, with a filament voltage anywhere between 5.5 volts and 7.5 volts.

When operated as an amplifier, the type 6F8G tube may have a plate voltage as high as 250 volts; with this voltage and with a C bias of —8 volts, the plate current will be about 9 ma.

The a.c. plate resistance of a type 6F8G tube is about 7,500 ohms, its mutual conductance is about 2,600 micromhos, and its amplification factor is about 20. Of course, the tube can be operated at other plate voltages, but such operation will give different values for the important ratings of the tube.

The grid-cathode inter-electrode capacity for each triode section is about 3 mmfd. The plate-cathode capacity for each triode section is about 3.5 mmfd. The grid-plate capacity for each triode section is about 4 mmfd.

The input capacity of a triode section is always higher than the grid-cathode capacity when the tube is in operation; actually, the input capacity is the sum of the grid-cathode capacity, the stray grid circuit capacities and a value equal to the grid-plate capacity multiplied by the true amplification of the stage.

A small capacity, less than .4 mmfd., exists between any electrode in one triode section and any electrode in the other triode section, but the effects of these capacities will be negligible in our experiments.

INSTRUCTIONS FOR PERFORMING EACH EXPERIMENT

1. **Read the entire experiment, giving particular attention to the discussion.**
2. **Perform each step of the experiment and record your results. Whenever a measurement is specified, be sure to make it exactly according to the "OPERATING INSTRUCTIONS FOR N.R.I. TESTER" given for that type of measurement in this manual or in the previous manuals.**
3. **Study the discussion of the experiment and analyze your results.**
4. **Answer the report statement for the experiment. It will always be on the last page of the manual.**

EXPERIMENT 41

Purpose: **To build an a.f. oscillator and check its performance with the N.R.I. Tester and a headphone; to demonstrate that a condenser can be used to tune the a.f. oscillator circuit to a desired frequency.**

Preliminary Discussion: The schematic circuit diagram of the a.f. oscillator which you build for this experiment is shown in Fig. *3*. Observe that this circuit employs only one triode section of the type 6F8G tube. The iron-core transformer serves to couple the plate circuit to the grid circuit in the proper manner for oscillation. The filament and plate supply voltages for the tube are obtained from your power pack.

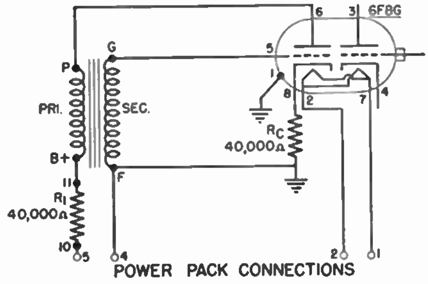


FIG. 3. Schematic circuit diagram of the a.f. oscillator which you build as a part of Experiment 41.

The schematic circuit diagram is presented for reference purposes and to help you understand how an audio oscillator of this type works. You will assemble the oscillator according to the detailed step-by-step instructions and semi-pictorial diagrams which will now be given.

✓ *Step 1. To mount on the chassis the parts needed for the a.f. oscillator,* carry out the following instructions:

✓ *a.* Place before you the following parts:

Type 6F8G vacuum tube (Part *5-1*).
Octal-type tube socket (Part *5-2*).
Audio transformer (Part *5-4*).
Cadmium-plated steel chassis (Part *5-5*).
Headphone unit (Part *5-8*).
.001-mfd. paper condenser (Part *5-10*).
.01-mfd. paper condenser (Part *5-11*).
.05-mfd. paper condenser (Part *5-12*).
Rubber grommet (Part *5-15*).
Machine screws and nuts (Parts *5-16A* and *5-16B*).
.25-mfd. paper condenser (Part *3-2A*).
Two 40,000-ohm resistors (Parts *3-6A* and *3-6B*).
Six-lug terminal strip (Part *3-12*).
Soldering iron, solder, hook-up wire, and all tools used in previous experiments.

✓ *b.* To identify the chassis holes through which hook-up wire will be run, place your chassis bottom side up in the position shown in Fig. *4*, then locate holes *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *j* and *k* on your chassis and identify each with metal-marking crayon exactly as indicated in Fig. *4*.

Turn the chassis over, and identify these eleven holes on top of the chassis with metal-marking crayon in the same manner, being sure that your marking above the chassis for each hole is the same as the marking underneath the chassis (see Fig. *6*).

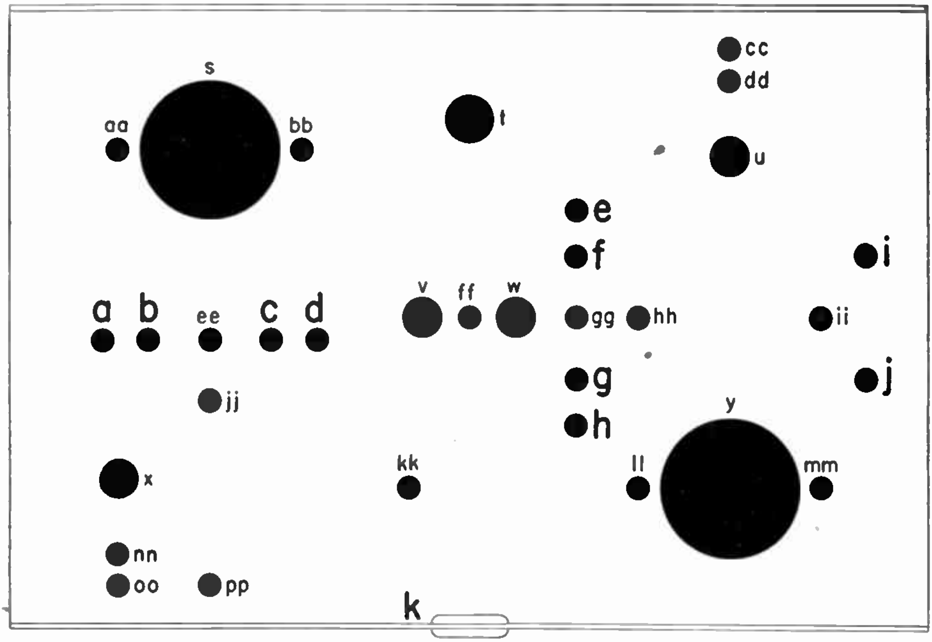


FIG 4. Bottom view of the oscillator chassis supplied to you in this Radio Kit, with all holes identified. Holes *a, b, c, d, e, f, g, h, i, j* and *k* should be identified on both sides of your own chassis with metal-marking crayon exactly as indicated here, but do not make any other marks on your chassis at this time.

Do not place any other markings on your chassis at the present time. The remaining holes are used for mounting parts, and Fig. *4* is an adequate guide for locating these holes.

c. Insert the rubber grommet (Part *5-15*) in hole *k*, after referring to Fig. *4* to locate this hole. It is on one side of the chassis.

d. Mount the 6-lug terminal strip underneath the chassis in holes *kk* and *ll*, by inserting the machine screws through these holes from the top of the chassis, placing the mounting holes of the strip over the projecting screws underneath the chassis in such a way that the lugs are farthest away from the rubber grommet, as shown in Fig. *5*, then placing nuts on the screws and tightening with pliers and a screwdriver.

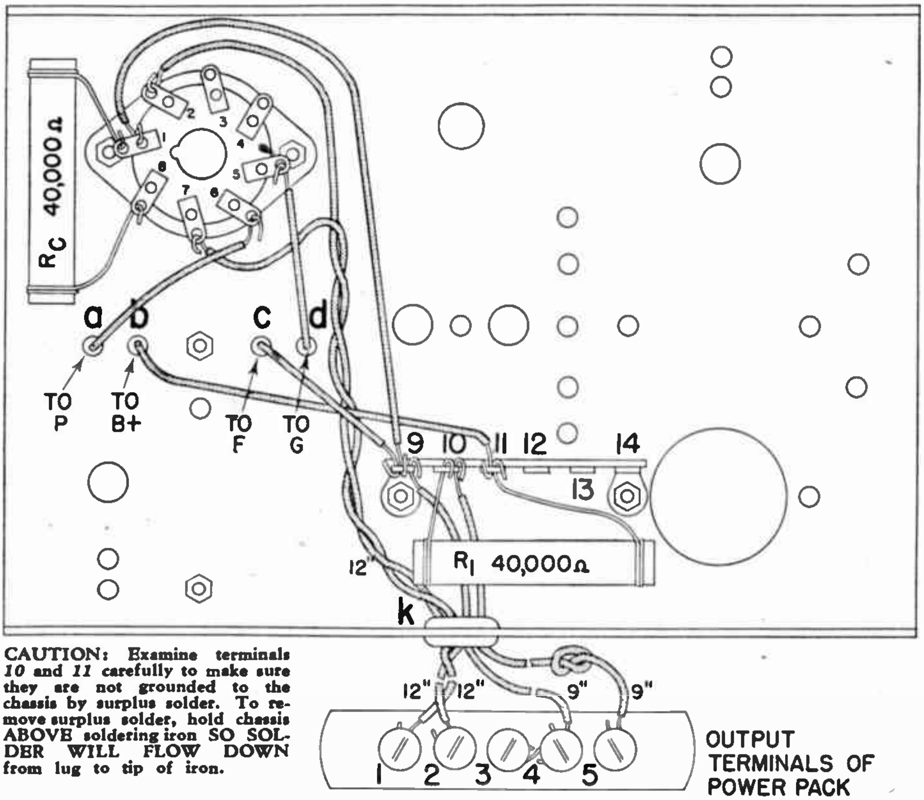
e. Mount the tube socket in hole *s* by inserting it in its hole from the bottom of the chassis in such a way that the aligning slot is next to hole *aa*, then fastening the socket to the chassis with machine screws and nuts.

f. Mount the audio transformer on top of the chassis in holes *ee* and *pp*, in a position such that the transformer lugs are approximately above holes *a, b, c* and *d*. The correct position of the transformer is shown in Fig. *6*.

Step 2. Complete the wiring of your a.f. oscillator in the following manner, making *temporary* soldered hook joints unless otherwise specified:

a. Identify the terminals of the 6-lug terminal strip by placing the numbers *9, 10, 11, 12, 13* and *14* on the chassis near these terminals with metal-marking crayon in exactly the manner shown in Fig. *5*.

Although tube socket terminal numbers are embossed on the bakelite portion of the socket already, you may find it easier to identify the socket lugs if you also mark these numbers on the chassis alongside the lugs with metal-marking crayon.



CAUTION: Examine terminals *10* and *11* carefully to make sure they are not grounded to the chassis by surplus solder. To remove surplus solder, hold chassis ABOVE soldering iron SO SOLDER WILL FLOW DOWN from lug to tip of iron.

FIG. 5. Semi-pictorial bottom view of the oscillator chassis, showing how parts and wires should be arranged for the a.f. oscillator which you construct for Experiment 41.

✓ *b.* Cut two 12-inch lengths of red hook-up wire, connect one length to socket terminal *7*, with a *permanent* soldered hook joint, connect the other length to socket terminal *2*, with a *permanent* soldered hook joint, bend this length around the tube socket as shown in Fig. *5*, then twist the two wires together for the remainder of their length as indicated in Fig. *5*. A simple method of twisting wires together neatly with your fingers is shown in Fig. *7*. Bring the two twisted leads through the rubber grommet in hole *k*, as indicated in Fig. *5*.

✓ *c.* Connect a 9-inch length of red hook-up wire to terminal *9* with a *permanent* hook joint but do not solder this joint yet. Run this wire out of the chassis through the rubber grommet in hole *k*.

✓ *d.* Connect a 9-inch length of red hook-up wire to terminal *10* with a *permanent* hook joint, without soldering. Bring this lead out through the

IMPORTANT: Resistor and condenser leads which are more than two inches long should be cut to a length of approximately two inches. This applies to all remaining experiments in your Practical Demonstration Course. Resistor and condenser leads in semi-pictorial diagrams may sometimes appear to be shorter than two inches, but this effect occurs because the leads are at an angle to the chassis. From now on, all connections which you make in your Practical Demonstration Course should be *temporary soldered joints.*

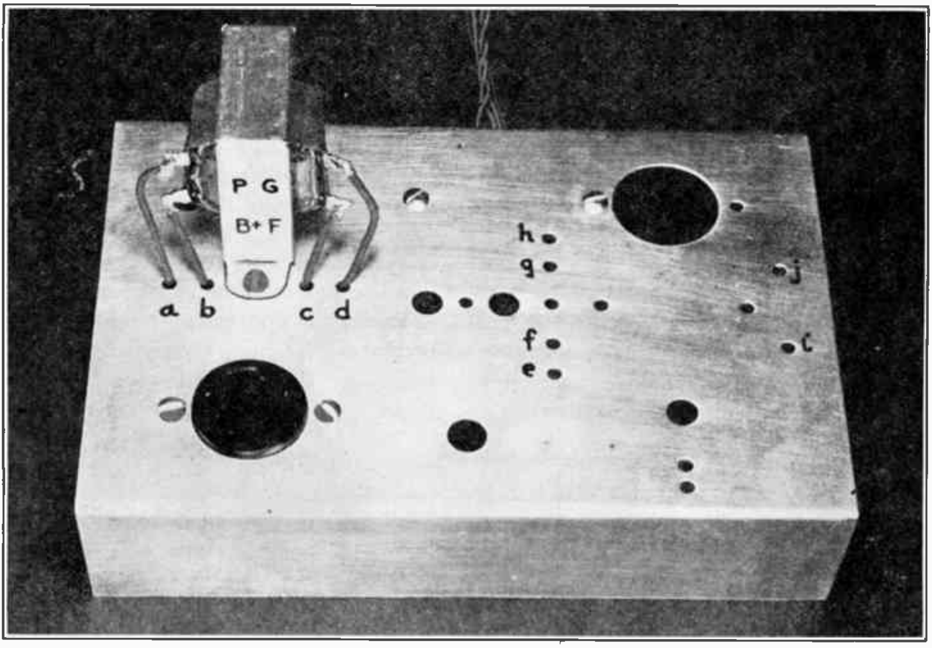


FIG. 6. Top view of the completed a.f. oscillator used in Experiment 41.

rubber grommet, and tie a simple knot about 2 inches from the end of the lead as indicated in Fig. *5*, to identify it as the B+ lead which is always to go on power pack output terminal *5*.

e. Connect a 40,000-ohm resistor (Part *3-6A*) between terminals *10* and *11* with temporary hook joints, soldering only terminal *10*. Adjust so neither the resistor nor its leads touch the chassis or other terminals.

f. Connect audio transformer terminal *F* (above the chassis) to terminal *9*. This connection is shown in Figs. *5* and *6*. Run the wire through chassis hole *c*, make temporary hook joints, and solder only at terminal *F*. The professional technique for making connections of this type involves straightening out several feet of wire from your roll of red hook-up wire, bringing the end of this wire through chassis hole *c* from the top of the chassis and connecting the wire to terminal *9*, then holding the wire alongside terminal *F*, cutting the wire enough above terminal *F* to permit forming a hook, then connecting to terminal *F*. This can be done much more rapidly than cutting the wire first to a specified dimension, hence lengths of leads will not be specified in future steps unless there is some special reason for having a particular length of wire.

g. Connect the *B+* terminal of the audio transformer to terminal *11* under the chassis, running the wire through chassis hole *b* and soldering both terminals. (Sometimes this terminal on an audio transformer is simply marked *B*.) Run this wire over the twisted filament leads but under the single wire going from hole *c* to *9*.

h. Connect audio transformer terminal *P* to socket terminal *6*, running the wire through chassis hole *a* and soldering both terminals.

i. Connect audio transformer terminal *G* to socket terminal *5*, running the wire through chassis hole *d* and soldering both terminals.

✓ *j*. Connect socket terminal *1* to terminal *9*, running the wire around the socket as shown in Fig. *5* and soldering both terminals. Place the wire in the lower hole of terminal lug *1*.

✓ *k*. Connect a 40,000-ohm resistor (Part *3-6B*) between socket terminals *1* and *8*, soldering both terminals. Place the resistor lead in the upper hole of terminal lug *1*, as indicated in Fig. *5*.

✓ *Step 3. Complete the assembly of the a.f. oscillator* by making power pack connections as follows:

✓ *a*. Connect the two twisted wires to output terminals *1* and *2* respectively of your power pack. These are filament supply wires, and their polarity is unimportant.

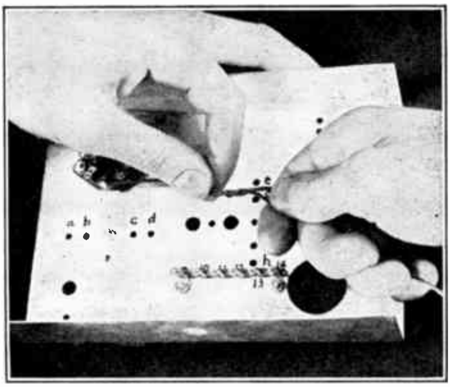


FIG. 7. Method of twisting the wires together to serve as filament leads for the a.f. oscillator. These leads will be left connected to socket terminals *2* and *7* for all ten of the experiments in this manual.

✓ *b*. Connect to output terminal *5* on your power pack the a.f. oscillator lead in which you previously tied a knot. This is the *B*+ lead.

✓ *c*. Connect the remaining a.f. oscillator wire to output terminal *4* on your power pack. This is the *B*— lead.

d. Insert the type 6F8G tube in its socket on the a.f. oscillator chassis. The power pack and a.f. oscillator unit should now appear as shown in Fig. *8*, if you have an a.c. power pack. Power pack connections are made in exactly the same manner for the d.c. power pack. (The wire which connects together output terminals *2*, *3* and *4* on the d.c. power pack should be left in position; likewise, the wire which connects output terminals *3* and *4* on the a.c. power pack should be left in position until you receive definite instructions to remove it. The external ground wire should be connected to terminal *3* in both cases whenever the power pack is used.)

Step 4. To check the operation of your assembled a.f. oscillator, use your N.R.I. Tester and the headphone unit (Part *5-8*) to listen to the a.f. signal between the chassis and the *G* terminal of the audio transformer, by following the instructions given in this manual for "LISTENING TO AUDIO SIGNALS." The red clip should go on terminal *G*, and the black clip should go on the chassis, as shown in Fig. *8*. Now turn on the power pack and the N.R.I. Tester. If you have assembled the a.f. oscillator correctly, you should hear a distinctly audible tone in the headphone after the tubes have warmed up.

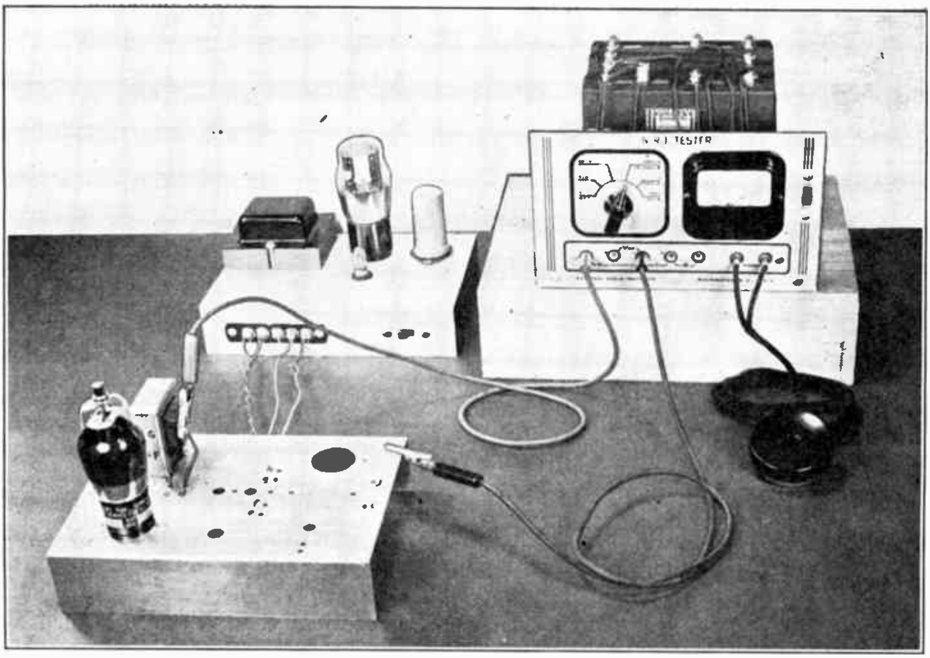


FIG. 8. This view shows how the a.f. oscillator is connected to the power pack, and how the N.R.I. Tester is used for listening to the audio output of the oscillator.

While the power pack and the N.R.I. Tester are still turned on, switch to the *30* × *V* range and note the effect upon volume. Disregard meter readings for the present. Switch momentarily to lower voltage ranges, but do not leave the selector switch at a lower range for more than a few seconds if it causes overloading of the meter.

Turn off the N.R.I. Tester, then turn off the power pack. Leave the test clips in position.

Step 5. To determine the effect which various condenser values connected between P and B+ have upon the frequency of the audio signal, first connect a .001-mfd. condenser (Part *5-10*) between the *P* and *B+* terminals of the audio transformer by means of temporary soldered lap joints. Listen to the signal again with the headphone and N.R.I. Tester (red clip on *G*, black clip on chassis, and selector switch at *100* × *V*). Try to decide whether the frequency (the musical pitch) of the signal is now higher or lower than it was without the condenser. If you leave one condenser lead disconnected, and make this connection momentarily several times while listening (by pushing on the body of the condenser with your fingers), the change in frequency will be easier to recognize.

Remove the .001-mfd. condenser from the audio transformer terminals (always be sure to turn off all power before making any circuit changes), connect a .05-mfd. condenser (Part *5-12*) to audio transformer terminals *P* and *B+* in its place, listen to the audio signal again, and note the effect which this higher capacity has upon the frequency of the audio signal.

Remove the .05-mfd. condenser from the audio transformer terminals, and connect in its place a .25-mfd. condenser (Part *3-2A*). Connect the .05-mfd. condenser across cathode resistor R_C (between socket terminals *1* and *8*). Again listen to the audio signal to determine the effect which this higher capacity value (.25 mfd.) has upon the frequency of the audio tone.

After turning off all apparatus, remove the test clips, remove the .25-mfd. condenser from the audio transformer terminals, and remove the .05-mfd. condenser from terminals *1* and *8*.

Discussion: Reference to the schematic circuit diagram for your a.f. oscillator (Fig. *3*) will show that the conventional by-pass condenser for cathode resistor R_C has been omitted, and no plate supply by-pass condenser has been used. These two by-pass condensers have been left out for the purpose of reducing the amount of feed-back, thereby improving the wave form of the a.f. signal produced by the oscillator. In other words, omission of these by-pass condensers makes the a.f. voltage of the oscillator have more nearly the desired perfect sine wave form.

This circuit produces oscillations at an audio frequency simply because each voltage change or surge in the plate circuit passes through the primary winding of the audio transformer and is transferred to the secondary or grid circuit, with the phase relationship being such that this feed-back voltage *reenforces* the grid voltage. Since the audio transformer reverses the phase of a voltage 180°, this means that the plate-cathode a.f. voltage of the tube must be about 180° out of phase with the grid-cathode a.f. voltage, if oscillation is to be secured.

Audio transformer connections must th efore be made exactly as specified e instructions in order to make a.f. oscillator work. In practi- dio work, when an audio oscillator will not oscillate because of improper connections to one of the audio transformer windings, the trouble can be cleared up by reversing the connections either to the primary or secondary winding.

In Step 5, the shunting of a condenser across the primary winding of the audio transformer adds to the distributed capacity of this winding. The primary winding has a definite inductance which, with the distributed capacity of the winding, determines the *highest* frequency which the oscillator will produce. Anything which increases either the inductance of the primary winding or the value of the capacity will *lower* the frequency; thus, placing a condenser across the primary winding should lower the output frequency.

Theoretically, any desired lower frequency can be obtained by shunting the correct capacity value across the coil. Actually, however, this statement holds true only within limits; if the capacity across the coil is made too large, the circuit stops oscillating. When this occurs, the coil inductance must be increased before the capacity is further increased.

Instructions for Report Statement No. 41. In the discussion, it was pointed out that in order for oscillation to occur, the a.f. plate voltage in your a.f. oscillator must be about 180° out of phase with the a.f. grid voltage. Since the audio transformer reverses the phase of a voltage (changes it 180°), this means that during normal oscillator operation the a.f. voltage which is fed back into the grid circuit is *in phase* with the a.f. grid voltage, and therefore reenforces the grid voltage.

For this report statement, you are to reverse the connections to the primary winding of the audio transformer, thereby reversing the phase of

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

LISTENING TO AUDIO SIGNALS

1. **Place the red probe in the left-hand V_{AC} jack, and place the black probe in the —V_{AC} jack.**
2. **Set the selector switch to *100 × V*.**
3. **Remove the jumper from the *PHONE* jacks, and plug the headphone tips into these two jacks.**
4. **Place the black clip on the a.f. terminal which is closest to or actually at chassis potential for a.f. signals, and place the red clip on the other a.f. terminal.**
5. **Turn on the apparatus (the power pack in your case), then turn on the N.R.I. Tester and listen to the signal. Remember that with apparatus employing heater-type tubes, you must wait about half a minute for tubes to warm up.**
6. **To increase the volume, switch to a lower voltage range, providing it does not make the meter swing off scale.**
7. **When through, turn off the N.R.I. Tester first, then turn off the apparatus, remove the test clips from the a.f. terminals, pull out the test probes, remove the phone tips from the *PHONE* jacks, and replace the U-shaped jumper in the *PHONE* jacks. Accurate measurements cannot be made while the headphone is plugged in.**

the a.f. voltage which is fed back into the grid circuit. You probably know already what to expect when this is done, but by actually carrying out this change, you will impress its effect indelibly upon your mind.

To reverse the primary winding connections, first unsolder the lead which is on the *P* terminal of the audio transformer. Now disconnect the lead from the *B+* terminal of the audio transformer, extend this lead about 1 inch with a short piece of hook-up wire, and connect it to the *P* terminal. Finally, connect to the *B+* terminal the lead which you removed from the *P* terminal. No condenser will be used across the primary winding for this test. Place your test clips on the *G* terminal and the chassis, and listen for the audio tone just as before, after turning on your apparatus. You can now answer Report Statement No. 41, which merely asks you to check what you heard after making this test.

Finally, restore the original connections to the audio transformer, make a final listening check to be sure your oscillator is operating normally, and turn off the N.R.I. Tester and the power pack.

EXPERIMENT 42

Purpose: **To assemble an a.f. amplifier stage and connect it to amplify the output signal of your a.f. oscillator; to show that the gain provided by the a.f. amplifier stage increases as the resistance of its plate load is increased.**

Step 1. To assemble an a.f. amplifier stage on your chassis and connect it to the a.f. oscillator stage already on that chassis so as to secure the circuit shown in Fig. 9A, carry out the following step-by-step procedure:

a. Place before you the following parts:

Two .25-mfd. condensers (Parts *3-2A* and *3-2B*).
1,000-ohm resistor (Part *3-5A*).
Two 40,000-ohm resistors (Parts *3-6C* and *3-6D*).
18,000-ohm resistor (Part *1-16*).
1,000-ohm potentiometer (Part *3-8*).
Grid clip (Part *5-3*).

b. After removing the 6F8G tube from its socket, mount the 1,000-ohm potentiometer (Part *3-8*) in hole *t* on the chassis (see Fig. *4*) by removing the nut, inserting the potentiometer shaft in this hole from the bottom, then replacing the nut on the shaft projecting above the chassis and tightening with ordinary pliers while holding the potentiometer in such a position that its lugs are pointing toward the rubber grommet underneath the chassis. Identify the three potentiometer terminals by placing the numbers *15, 16* and *17* on the chassis near the lugs with metal-marking crayon in the manner shown in Fig. *10*.

To ground the control arm of the potentiometer, solder a wire to the center terminal *(16)*, fasten the other end to ground lug *9*, and solder lug *9* after placing the other leads.

There is no need to disconnect the four wires from the power pack during this procedure, for the wires will bend readily when you turn the oscillator chassis over.

c. Connect a 1,000-ohm resistor (Part *3-5A*) between socket terminals *1* and *4*, arranging the leads so the resistor does not touch the chassis.

d. Connect a .25-mfd. condenser (Part *3-2A*) between socket terminal *4* and terminal *14*. The body of the condenser can touch the chassis, but the leads should be well away from other leads and terminals. This condenser (C_2) is now in parallel with 1,000-ohm resistor R_3, as called for in the circuit diagram of Fig. *9A*, for socket terminal *1* is connected to terminal *9*, and *9* is connected to *14* through the chassis.

e. Connect a .25-mfd. condenser (Part *3-2B*) between potentiometer terminal *17* and terminal *11*.

f. Connect a 6½-inch length of red hook-up wire to potentiometer terminal *17* after first inserting the wire through chassis hole *e* from the top of the chassis. To the other end of this wire (projecting above the chassis), connect the grid clip (Part *5-3*) by pushing the insulation back from the end of the wire, bending the end of the wire at right angles about ¼ inch, inserting the end of the wire into the hole in the clip from underneath, bending the wire back along the top of the clip, pushing the insulation back over the wire up to the hole, bending the pointed tabs of the clip around the insulation, then soldering the exposed end of the wire. Details of this grid clip connection are shown in Fig. *11*.

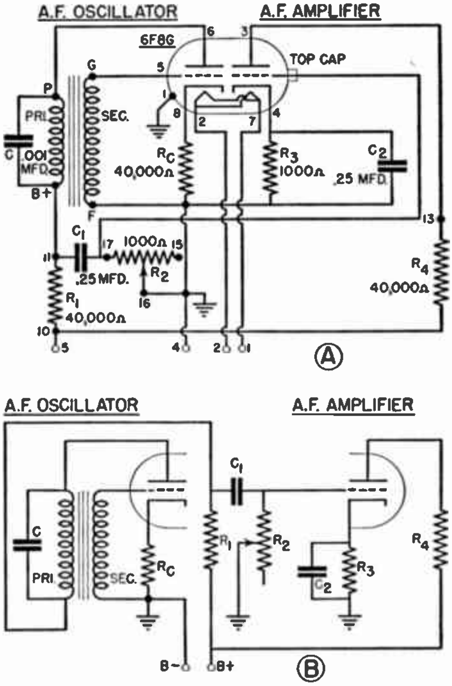


FIG. 9. Schematic circuit diagram (*A*) for the combination a.f. oscillator and a.f. amplifier which you assemble for Experiment 42. The left-hand triode section of the 6F8G tube serves the a.f. oscillator, while the right-hand triode section serves the a.f. amplifier. At *B* is a simplified schematic diagram of this same circuit, with the two triode sections separated just as if they were two individual triode tubes; in this spread-out form, the circuits are easier to recognize.

g. Connect socket terminal *3* to terminal *13*.

h. Connect a 40,000-ohm resistor (Part *3-6C*) between terminals *10* and *13* by means of temporary soldered *lap* joints. The bottom of your chassis should now appear as shown in Fig. *10*.

i. Connect a .001-mfd. condenser (Part *5-10*) between the *P* and *B+* terminals of the audio transformer.

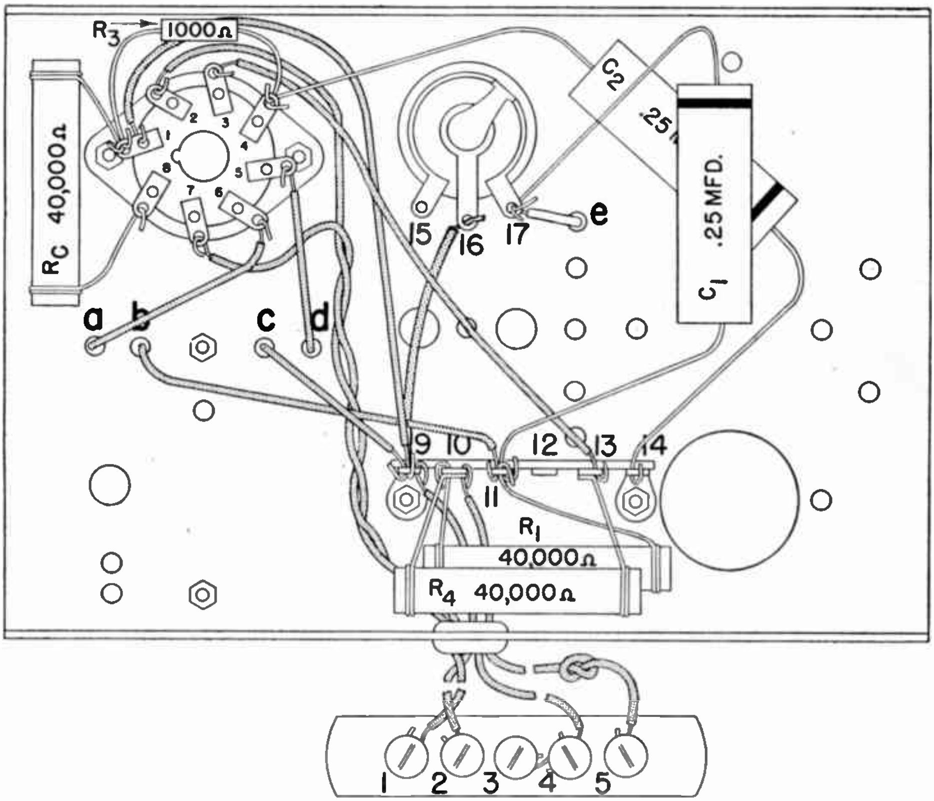


FIG. 10. Semi-pictorial bottom view of the chassis, showing how all parts and wires are arranged for the combination a.f. oscillator and a.f. amplifier circuit employed in Experiment 42. On this and future semi-pictorial diagrams of this type, terminal numbers may be in different positions than the numbers on your chassis, but this is done merely for clearness in the diagram. Once you place a number on your chassis, do not remove it.

With this condenser, your a.f. oscillator will have a frequency of about 800 cycles.

j. Replace the 6F8G tube in its socket and push the grid clip over the top cap of the tube. If necessary, the clip may be opened up slightly so it will fit over the top cap.

Step 2. To measure the a.f. output voltage of your audio amplifier stage for various plate load resistance values when the a.f. input voltage is 1 volt, first check the calibration of your N.R.I. Tester in the usual manner. Be sure to remove the headphone tips and replace the U-shaped jumper in the *PHONE* jacks when checking the calibration. Now read carefully the instructions given in this manual for "A.F. VOLTAGE MEASUREMENTS." You are expected to follow these instructions in the future whenever making a.f. measurements, for detailed instructions will not always be given in the experiments.

Since you now have the circuit shown in Figs. *9A* and *9B,* in which there is a 40,000-ohm plate load resistance (R_4) in the audio amplifier stage, your first a.f. measurement will be for this plate load value.

Place the red clip on the grid clip of your 6F8G tube, place the black clip on the a.f. oscillator chassis, leave the selector switch at *100 × V,* check the four power pack leads to be sure

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

A.F. VOLTAGE MEASUREMENTS

1. **Check the calibration of the N.R.I. Tester in the usual manner, as instructed in previous manuals. Be sure the U-shaped jumper is in the *PHONE* jacks during calibration. Tap the meter lightly with your finger during calibration to minimize bearing friction. Place the test probes in the V_{AO} jacks (black in $-V_{AO}$).**
2. **Practically all a.f. measurements in these experiments will be made with the *V* or *3* × *V* range. Always try both ranges, and use whichever range gives the *higher result in volts* (not the higher scale reading).**

   Important: Always start an a.f. measurement with the *100* × *V range,* and switch to a lower range only after you are certain that all tubes have reached normal operating conditions. This is necessary because the high d.c. voltages which are sometimes present at a.f. terminals during the initial warming-up period might overload the meter on a lower range, temporarily destroying the tester calibration. If you accidentally make the meter swing off-scale through forgetting to switch initially to *100* × *V,* be sure to correct the calibration by moving the calibrating clip temporarily to —4½C, then replace the clip on —9C.
3. **Read a.f. voltages on the *AC* scale in exactly the same manner as for a.c. measurements.**
4. **If a scale reading above 5.5 is obtained with the *3* × *V* range, you can: 1. Estimate the value as being a few volts higher than 16.5 volts; 2. Switch to the *30* × *V* range and read as best you can, though it will be very difficult to get an accurate reading because the pointer is below *1* on the scale; *3.* Insert a 10-megohm voltage multiplier resistor in series with the tester leads while using the *3* × *V* range, to convert this to a *6* × *V* range and thus secure an easy-to-read on-scale reading. (Detailed instructions for increasing a voltage range in this manner were given in the previous manual.)**

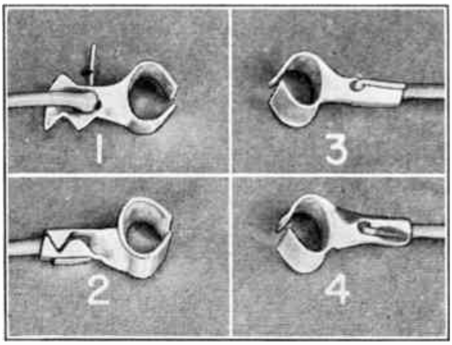


FIG. 11. The four important steps in connecting the grid clip for the type 6F8G tube to the end of a length of hook-up wire are shown here.

all connections are still secure and no leads are shorting at the power pack terminal strip, then turn on the power pack and the N.R.I. Tester. Half a minute later switch to the *V* range and rotate the potentiometer on the a.f. oscillator chassis with a screwdriver while watching the meter reading. The pointer should move from zero at one extreme position of the potentiometer to about 2 volts for the other extreme position.

To set the potentiometer accurately to an a.f. input voltage of exactly 1 volt, first rotate the potentiometer in a counter-clockwise direction as far as it will go, so as to bring the meter to *0*. If the pointer does not move exactly to *0* on the *AC* scale now when the meter is tapped lightly, adjust the knob at the back of the meter to secure this condition; this slight change in the knob setting will make measurement of low a.c. voltages more accurate without appreciably affecting the general calibration of the tester. Now rotate the potentiometer on the a.f. oscillator chassis in a clockwise direction until the meter reads exactly 1 volt on the *AC* scale. Do not change the setting either of this potentiometer or of the tester adjustments for the remainder of this experiment.

✓ *Step 3. To measure the a.f. load voltage for a 40,000-ohm plate load resistor,* set the a.f. oscillator chassis on its back side so that under-chassis terminals are accessible, set the selector switch at *100* × *V*, place the red clip on socket terminal *3*, leave the black clip still on the chassis, turn on the power pack and the N.R.I. Tester, switch to the *3* × *V* range half a minute later, read the meter on the *AC* scale, multiply the reading by 3 and record your result in Table *42* as the a.f. load voltage for a 40,000-ohm plate load. Return the selector switch to *100* × *V*, turn off the N.R.I. Tester, and turn off the power pack without changing anything else.

✓ *Step 4. To measure the a.f. load voltage for a 20,000-ohm load,* first connect another 40,000-ohm resistor (Part *3-6D*) in parallel with the 40,000-ohm resistor already connected to terminals *10* and *13*, using soldered lap joints. Turn on the power pack, turn on the N.R.I. Tester, half a minute later set the selector switch at *3* × *V*, read the meter on the *AC* scale, multiply your reading by 3, and record your result in Table *42* as the a.f. load voltage for a 20,000-ohm load. Set the selector switch back to *100* × *V*, turn off the N.R.I. Tester, and turn off the power pack.

✓ *Step 5. To measure the a.f. load voltage for approximately a 10,000-ohm plate load resistance,* first connect an 18,000-ohm resistor (Part *1-16*) in parallel with the two 40,000-ohm resistors already connected to terminals *10* and *13*. Turn on the power pack, turn on the N.R.I. Tester, half a minute later set the selector switch to *3* × *V*, read the meter on the *AC* scale, multiply the reading by 3, and record your result in Table *42* as the a.f. load voltage for a 10,000-ohm load. Set the selector switch back to *100* × *V*, turn off the N.R.I. Tester, and turn off the power pack.

✓ *Step 6. To measure the a.f. load voltage for an 80,000-ohm load,* first remove the two 40,000-ohm resistors and the 18,000-ohm resistor which are connected to terminals *10* and *13*. Now connect the two 40,000-ohm resistors in series between terminals *10* and *13* by using terminal *12* as an anchor point. In other words, connect one 40,000-ohm resistor between terminals *10* and *12* with soldered lap joints, and connect the other 40,000-ohm resistor between terminals *12* and *13* with soldered lap joints. Adjust the resistors carefully so neither of them touches the chassis. Turn on the power pack, turn on the N.R.I. Tester, half a minute later set the selector switch to *3* × *V*, read the meter on the *AC* scale, multiply the reading by 3, and record your result in Table *42* as the a.f. load voltage in volts for an 80,000-ohm plate load. Set the selector switch back to *100* × *V*, turn off the N.R.I. Tester, and turn off the power pack.

Step 7. Make a graph of load resistance plotted against the gain of your amplifier stage, by using your a.f. voltage values as gain values (you will learn in the discussion that the gain is the same as your measured value of a.f. load voltage). Use the same procedure employed for making graphs in previous experiments; in other words, put a dot on Graph *42* for each of your four measured values, then draw a smooth curve through or near these four dots and through the zero point on Graph *42*.

Discussion: Reference to the schematic circuit diagram in Fig. *9B* will give you a better understanding of the circuit you are now using. The 800-cycle a.f. plate current of the a.f. oscillator section flows through 40,000-ohm resistor R_1, developing across this resistor a corresponding a.f. voltage. Condenser C_1 and potentiometer R_2 provide a shunt path to ground, and signals taking this path develop across R_2 an a.f. voltage which is applied between the grid and cathode of the a.f. amplifier stage. The potentiometer is used as a rheostat; by adjusting it, the a.f. voltage drop across the potentiometer can be made exactly 1 volt, so that the a.f. input voltage of the audio amplifier stage is 1 volt.

This a.f. input voltage produces a corresponding a.f. plate current in the amplifier section of the 6F8G tube. This a.f. plate current flows through plate load resistor R_4, developing across this resistor the a.f. output voltage which we measure in this experiment for four different values of R_4 (we actually measure the voltage between plate terminal *3* and the chassis, but this is equivalent to measuring across the plate load resistor because the 10-mfd. output filter condenser in the power pack connects the chassis to the plate supply end of R_4 insofar as a.f. signals are concerned).

The actual gain or amplification provided by an a.f. amplifier stage is equal to the a.f. output voltage divided by the a.f. input voltage. Since we have adjusted the a.f. input voltage to exactly 1 volt, the a.f. output voltage value in volts will also be the gain of the stage. The values which you recorded in Table *42* thus represent the gain of your a.f. amplifier stage under the various conditions.

Your results for this experiment can be analyzed most readily by examining the curve which you obtained on Graph *42* for your values. This curve should have the same general shape as the N.R.I. curve plotted for comparison on this graph, but need not have the same values. Observe that the gain is low for low plate load resistance values, and increases rather rapidly at first with increases in plate load resistance. As load resistance is increased, however, the curve tends to flatten out and approach the theoretical amplification factor of the tube itself.

The rated amplification factor of each triode section in the 6F8G tube is 20, but we cannot expect to make experimental results check with rated values because of normal manufacturing tolerances and because of the difficulty encountered in reading low values accurately on the *AC* scale of the meter. Keep in mind that during the remaining experiments in your Practical Demonstration Course, the important thing is to obtain a *change* in value *in the correct direction*, rather than to obtain any specific measured value.

Now let us consider the reasons why the actual amplification or gain of a stage is less than the rated amplification factor of the tube. First of all, we know that if an a.c. voltage of 1 volt is applied to the grid of the tube, it will be equivalent to a plate circuit a.c. voltage of 1 volt multipled by the amplification factor (μ) of the tube. If we could utilize all of this a.c. plate voltage, the gain of the tube would be equal to the rated amplification factor of the tube. This a.c. plate voltage must send current through the a.c. plate resistance and the plate load resistance, however, and the voltage drop across the a.c. plate resistance reduces the amount of a.c. voltage available across the load.

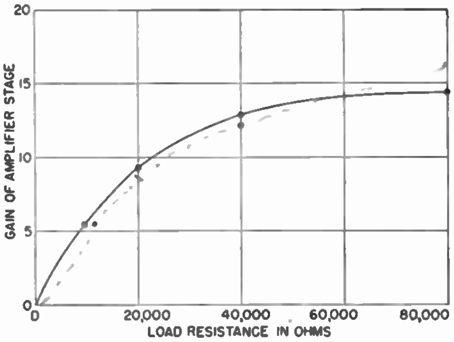
Under the conditions of this experiment, the a.c. plate resistance of the tube is approximately 7,000 ohms. The 20-volt a.f. plate circuit voltage (1 volt multiplied by the rated amplification factor of 20) is therefore divided between the 7,000-ohm a.c. plate resistance and whatever load resistance value we are using.

For a 10,000-ohm load, the total plate circuit resistance is 7,000 plus 10,000, or 17,000 ohms. The proportion of the total 20 volts available across the 10,000-ohm load will therefore be in the ratio of 10,000 to 17,000, and we can expect to get only about 11.7 volts across a 10,000-ohm load. For the reasons given in the next paragraph, however, your a.f. output voltage value for a 10,000-ohm load may be considerably lower than this value, just as is the N.R.I. value in Table 42. The actual computation is: (10,000 ÷ 17,000) × 20 = 11.7.

For an 80,000-ohm load, the total plate circuit resistance is 7,000 + 80,000, or 87,000 ohms. For this load, the computed a.f. plate load voltage is 18.4 volts: (80,000 ÷ 87,000) × 20 = 18.4. Your value for an 80,000-ohm load need not be anywhere near this value, as long as it is definitely higher than your value for a 10,000-ohm load, because your type 6F8G tube may have an amplification factor considerably different from the rated value of 20 due to normal manufacturing tolerances. Furthermore, the 7,000-ohm value which we estimated roughly as being the a.c. plate resistance may actually be at least 20% different from this assumed value, making the computations inaccurate. Actually, the a.c. plate resistance for this experiment is considerably higher than 7,000 ohms, because we are using a lower plate voltage than the normal 250-volt value for this tube.

STEP	PLATE LOAD IN OHMS	YOUR VALUE OF A.F. LOAD VOLTAGE IN VOLTS	N.R.I. VALUE OF A.F. LOAD VOLTAGE IN VOLTS
3	40,000	12.0	12.6
4	20,000	9.0	9.3
5	10,000	5.5	5.7
6	80,000	16.5V	14.4

TABLE 42. Record your results here for Experiment 42. If a meter reading higher than 5.5 is obtained for Step 3 or Step 6 while using the 3 × V range, corresponding to a voltage higher than 16.5 volts, you can either estimate the voltage as being slightly higher than 16.5, switch to the 30 × V range, or use a 10-megohm multiplier resistor in series with one test lead.



GRAPH 42. When you plot on this graph your own results for Experiment 42, you should obtain a curve having the same general appearance as the N.R.I. curve already drawn here, but you need not necessarily obtain the same curve.

Observe that 1,000-ohm cathode resistor R_3 for your amplifier stage is shunted by .25-mfd. condenser C_2. Ordinarily we expect that a by-pass condenser has considerably lower reactance than its shunt resistors, but the reactance of this condenser is only about 800 ohms at the 800-cycle frequency being used. This means that some a.f. voltage is developed across the cathode resistor and its by-pass condenser when the a.f. plate current is fairly high, such as for low plate load resistance values. This a.f. voltage causes degeneration, making the amplification of the stage lower than the normal value for that plate load resistance. (At N.R.I., when this cathode resistor was shunted with an 8-mfd. condenser while using an 80,000-ohm plate load resistance, the gain jumped to 17.)

The important thing to remember in connection with this experiment is that in a resistance-capacity coupled a.f. amplifier stage, a high plate load resistance value is necessary if approximately the full amplification capability of the tube is to be obtained.

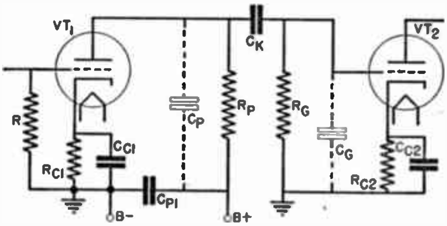


FIG. 12. Schematic circuit diagram of a typical resistance-capacity coupled audio amplifier circuit such as is widely used in radio receivers. In Experiment 43, you work with the electrical equivalent of this circuit.

Instructions for Report Statement No. 42. With an 80,000-ohm plate load resistance and with your apparatus connected exactly as it was for Step 6, remove the .25-mfd. cathode by-pass condenser by unsoldering one lead of the condenser which is connected between socket terminal *4* and terminal *14* underneath your a.f. oscillator chassis, and measure the a.f. plate voltage with this condenser removed.

Compare your result with that which you recorded in Step 6 of Table *42* for the corresponding condition with the condenser in place; if you are not entirely sure that a change has occurred, reconnect and disconnect the condenser momentarily while watching the meter, either by pushing on the condenser lead with a piece of wood or by holding the paper body of the condenser with your fingers while power is on. Do not touch any leads or terminals with your fingers while doing this.

After you are certain you know how the a.f. plate voltage changes when the cathode by-pass condenser is removed, answer Report Statement No. 42. Turn off all apparatus now, and remove the test probes from the N.R.I. Tester, but leave all other circuit connections as they are.

EXPERIMENT 43

Purpose: **To show that reducing the capacity of the coupling condenser in an a.f. amplifier stage reduces the over-all gain of the stage at low audio frequencies; to show that shunt capacities in the output circuit of an a.f. amplifier stage reduce the over-all gain of the stage at high audio frequencies.**

Preliminary Discussion: A typical resistance-capacity coupled amplifier circuit is shown in Fig. *12*. In this circuit, R_P is the plate load resistor for the stage employing tube VT_1, C_K is the plate-to-grid coupling condenser, and R_G is the grid return resistor for the stage employing tube VT_2.

In this experiment, you will set up with your apparatus a circuit which is equivalent to that shown in Fig. *12*, and make measurements which tell how the circuit will behave under various conditions. To do this, you add to your audio amplifier stage a coupling condenser equivalent to C_K and a grid resistor equivalent to R_G, and first determine what effect the value of C_K has upon the a.f. voltage developed across R_G.

In another step, you introduce a capacity which essentially duplicates the effect of stray circuit capacities C_P and C_G, to determine what effect these stray capacities have upon the over-all gain of the stage.

Step 1. To check the over-all gain of your audio amplifier stage for two different coupling condenser values at a frequency of about 180 cycles, first place before you the a.f. oscillator which you assembled according to the schematic diagram in Fig. *9A* and modified according to the instructions in Step 6 of Experiment 42 so as to change R_4 from 40,000 ohms to 80,000 ohms.

To change this oscillator so it will produce a frequency of about 180 cycles, remove the condenser from audio transformer terminals *P* and *B+*, and connect instead to these terminals a .05-mfd. condenser.

Remove from your audio amplifier circuit (Fig. *9A*) the .25-mfd. cathode by-pass condenser which is connected between terminal *14* and socket terminal *4*. Connect one lead of this .25-mfd. condenser to socket terminal *3*, connect the other condenser lead to one lead of your 100,000-ohm resistor (Part *5-13*) by means of a temporary soldered lap or hook joint, then connect the other resistor lead to terminal *14*, so that the a.f. amplifier portion of your set-up has the circuit shown in Fig. *13*. Adjust these two parts so that their leads do not touch the chassis or other parts.

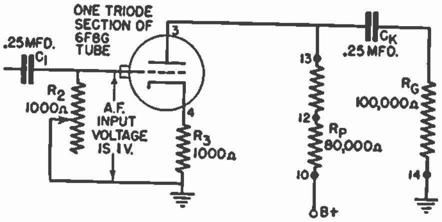


FIG. 13. Schematic circuit diagram of the a.f. amplifier set-up which you employ in Experiment 43 to duplicate a resistance-capacity coupled audio amplifier circuit.

Note: A 100,000-ohm resistor is sometimes marked 100M or .1 MEG. by resistor manufacturers or on circuit diagrams.

Adjust the a.f. input voltage of your a.f. amplifier stage to 1 volt just as you did in the previous experiment (with the red clip on the grid clip, with the black clip on the oscillator chassis, and with the selector switch first at *100 × V* and then at *V*, adjust the potentiometer on the oscillator chassis until the meter reads exactly 1 volt on the *AC* scale).

Measure the a.f. output voltage across the 100,000-ohm resistor you just added to your amplifier circuit by moving the red clip to the common junction of the .25-mfd. condenser and 100,000-ohm resistor, leaving the black clip on the chassis, and setting the selector switch to the *3 × V* range. Be sure the red clip does not touch other leads or terminals. Record your measured value of a.f. voltage in Table *43*.

To measure the a.f. output voltage when the value of the coupling condenser is .001 mfd., first remove the .25-mfd. condenser which was connected between socket terminal *3* and the 100,000-ohm resistor lead, and connect in its place a .001-mfd. condenser. Without changing any other connections, measure the a.f. output voltage across the 100,000-ohm resistor as previously instructed, using the *V* range, and record your result in Table *43* as the a.f. output voltage value for the condition wherein C_K is .001 mfd.

Step 2. To determine the effect of a shunt capacity upon the over-all gain of your audio amplifier stage at a frequency of about 800 cycles when using a .25-mfd. coupling condenser, first remove the .001-mfd. condenser which is connected between socket terminal *3* and the 100,000-ohm resistor lead, and connect in its place again the .25-mfd. condenser. Now remove the .05-mfd. condenser (added in Step 1 of this experiment) from the *P* and *B+* terminals of the audio transformer, and connect the .001-mfd. condenser to these terminals so as to restore the circuit of Fig. *9A* and make the a.f. oscillator deliver a frequency of about 800 cycles.

To check the gain at 800 cycles first without any shunt capacity in the amplifier circuit, adjust exactly to 1 volt the a.f. input voltage to the amplifier stage as previously instructed, then measure the a.f. output voltage across the 100,000-ohm resistor while using the $3 \times V$ range of the N.R.I. Tester, and record your result in Table 43, as the a.f. output voltage in volts when the frequency is 800 cycles and there is no shunt capacity.

Connect a .01-mfd. condenser between terminals *9* and *13* so as to provide a shunt capacity between the amplifier triode plate and ground, measure the a.f. output voltage again across the 100,000-ohm resistor while using the $3 \times V$ range, and record your result in Table *43* as the a.f. output voltage in volts when the frequency is 800 cycles and the shunt capacity (C_S) is .01 mfd.

Discussion: The N.R.I. values for Step 1 show that lowering the value of coupling condenser C_K from .25 mfd. to .001 mfd. makes the a.f. output voltage drop considerably; your own values for these two measurements should show the same thing. At 180 cycles, the .25-mfd. coupling condenser has a reactance of about 3,500 ohms, which is quite small in comparison with the 100,000-ohm value of the grid resistor. As a result, very little a.f. voltage appears across the coupling condenser, and most of the voltage is developed across the grid resistor. A .25-mfd. coupling condenser thus gives very nearly the maximum over-all gain which could be obtained from the amplifier tube when using the 80,000-ohm plate load resistor.

With a .001-mfd. coupling condenser, the condenser reactance at 180 cycles is about 880,000 ohms, much higher than the 100,000-ohm value of the grid resistor. Now most of the a.f. voltage is dropped across the coupling condenser, where it is of no use, and only a small portion is dropped across the grid resistor. This explains why the N.R.I. values of a.f. output voltage drop from 15.0 for the .25-mfd. condenser to 1.7 volts for the .001-mfd. coupling condenser.

The N.R.I. values for Step 2 show clearly that a shunt capacity connected between the amplifier triode plate and ground to duplicate the effects of inter-electrode and stray shunt capacities makes the a.f. output voltage drop. At higher frequencies than 800 cycles, there would be an even greater drop in a.f. output voltage when the shunt condenser is used.

Note that even though the circuits are identical for the first measurements in Steps 1 and 2, there is some difference in the N.R.I. values of output voltage. This is due simply to the fact that the wave form of the 180-cycle a.f. voltage used in Step 1 is different from the wave form of the 800-cycle voltage used in Step 2. Actually, the wave form at 180 cycles is an almost pure sine wave, while at 800 cycles it is distorted considerably from a sine wave (the peak in one direction is short and broad, and in the other direction is narrow and long).

STEP	CIRCUIT DATA	YOUR VALUE OF A.F. OUTPUT VOLTAGE IN VOLTS	N.R.I. VALUE OF A.F. OUTPUT VOLTAGE IN VOLTS
1	C_K = .25 MFD. f IS 180 CYCLES	12.8	15.0
	C_K = .001 MFD. f IS 180 CYCLES	2.0	1.7
2	NO SHUNT CAPACITY f IS 800 CYCLES	11.2.	11.7
	SHUNT CAPACITY C_S IS .01 MFD. f IS 800 CYCLES	9.6	8.1

TABLE 43. Record your results here for Experiment 43.

Instructions for Report Statement No. 43. According to Kirchhoff's Voltage Law for d.c. circuits, the sum of the three d.c. voltages in the plate circuit of your amplifier stage (the d.c. voltage drop across plate load resistor R_P, the voltage drop across the d.c. plate resistance of the triode tube section, and the d.c. voltage drop across 1,000-ohm cathode resistor R_3 (in Fig. *13*) should equal the d.c. output voltage of your power pack. You can measure all four of these d.c. voltages with the N.R.I. Tester and verify Kirchhoff's Law if you like, but you will only have to measure two of these d.c. voltages in order to answer Report Statement No. 43.

With your apparatus connected exactly as for the last measurement in Step 2 of this experiment, prepare the N.R.I. Tester for d.c. voltage measurements according to previous instructions, then measure the d.c. output voltage provided by your power pack. You can do this either by measuring between terminals *4* and *5* of the power pack or by placing the black clip on terminal *9* and the red clip on terminal *10* under the chassis of your oscillator. Remember that all apparatus must be turned off before you move the test clips.

Next, measure the d.c. plate voltage of the amplifier triode section (the plate-cathode voltage) by placing the red clip on socket terminal *3* and placing the black clip on socket terminal *4*. Compare the two d.c. voltage values you just measured, then answer Report Statement No. 43.

EXPERIMENT 44

Purpose: **To prepare and calibrate the N.R.I. Tester for r.f. measurements; to assemble an r.f. oscillator; to show that increasing the d.c. plate supply voltage of an r.f. oscillator causes increases in the r.f. voltage across the resonant circuit, the d.c. bias voltage across the grid resistor, and the d.c. plate current.**

Preliminary Discussion: Even under ideal laboratory conditions, radio frequency measurements are usually only approximate, for many factors tend to make r.f. measurements inaccurate and difficult. Fortunately, however, extremely accurate r.f. measurements are seldom required; experienced technicians who realize this fact and realize the limitations of their equipment do not expect too much precision.

In the circuit employed in the N.R.I. Tester, we have normal variations with frequency such as are encountered in all vacuum tube circuits of this type. The circuit has either regeneration or degeneration, depending upon the nature of the plate load. At audio frequencies, the .05-mfd. condenser which is shunted across the meter provides adequate compensation.

At radio frequencies, however, degeneration is sufficient to make the meter readings somewhat low. We have found from experience that meter readings beyond 4.5 on the *AC* scale correspond to r.f. input voltages high enough to swing the grid of the tube in the tester positive on peaks. The resulting grid current flow through the grid resistor increases the C bias and upsets the calibration of the tester, hence we must not allow the grid to swing positive. This is why you are instructed to switch to a higher voltage range during r.f. measurements whenever the pointer swings beyond 4.5 on the *AC* scale. You will learn, however, that this limitation does not prevent you from obtaining satisfactory results.

Here is the important general rule which you must keep in mind when making r.f. measurements: Try all three of the lowest voltage ranges (*V*, *3* × *V* and *30* × *V*), and use the one which gives the highest *voltage* value (not necessarily the highest scale reading). You cannot damage the instrument in this particular measurement by switching to too low a range, for grid current will develop a negative C bias which prevents overloading of the meter.

At radio frequencies, the grid-cathode inter-electrode capacity of the type 1C5GT tube in the N.R.I. Tester has such a low reactance in ohms that it becomes an appreciable shunt reactance across a portion of the voltage divider in the tester; this capacity is indicated as C_{GK} in Fig. *14A*, which shows the input circuit of the tester in simplified form as it is during r.f. and a.f. measurements when using the *3* × *V* range.

Capacity C_{GK} upsets the division of r.f. voltages in the tester, so that voltage *V* acting upon the grid and cathode of the type 1C5GT tube is no longer exactly ⅓ of the voltage being measured when the selector switch is set at *3* × *V*. However, by placing across the 6.7-megohm resistor an added capacity C_1 having a capacitive reactance which is one-half the capacitive reactance of grid-cathode capacity C_{GK}, we obtain a condenser voltage divider which divides the voltages in the ratio of 1 to 3 and thus corrects this r.f. condition without affecting the accuracy of other types of measurements.

You will receive instructions later in this manual for introducing this capacity and adjusting it to the correct value. With this correction, r.f. voltages up to 3 × 4.5 volts, or 13.5 volts, can be measured. (Remember that *AC* scale readings above 4.5 are not to be trusted during r.f. measurements, because of grid current.)

There will be a few occasions in which r.f. voltages higher than 13.5 volts will require measurement, but these r.f. values will rarely if ever be higher than 30 × 4.5, or 135 volts We must therefore be sure that voltage division is correct also for the *30 × V* range of the N.R.I. Tester.

When the selector switch of the N.R.I. Tester is set to *30 × V*, the simplified schematic diagram of the tester takes the form shown in Fig. *14B*. We still have grid-cathode capacity C_{GK} shunting a portion of the voltage divider, and a definite capacity value C_1 shunting the 6.7-megohm portion of the voltage divider. To secure correct voltage division on the *30 × V* range, the capacity across the 6.7-megohm and 3-megohm resistors must be 1/29 the capacity value of C_{GK}. This means that there must be a capacity across the 3-megohm resistor. It so happens that the capacities between the switch terminals and between the leads connected to the terminals are equivalent to a capacity C_2 which is just about the required value.

Thus, by the addition of a single capacity across the 6.7-megohm resistor, you can make your N.R.I. Tester provide satisfactory comparisons of r.f. voltage values on the three lowest voltage ranges. The only limitation to remember is that you must use the range which gives the highest voltage value. To help you in this connection, the range used to obtain the N.R.I. values given in the tables will usually be specified in the instructions.

Step 1. To prepare for the assembly of an r.f. oscillator, carry out the following steps in exactly the order indicated.

a. Remove the type 6F8G tube from its socket on the chassis, and disconnect the four leads from the power pack output terminals.

b. Remove the .001-mfd. condenser from the *P* and *B+* terminals of the a.f. transformer, unsolder the leads from all four a.f. transformer terminals, then remove the a.f. transformer from the chassis.

c. Turn the chassis over, and unsolder all of the connections which are on tube socket terminals *1, 3, 4, 5, 6* and *8*. This removes the 1,000-ohm resistor and the 40,000-ohm resistor; set these aside for future use. Do not remove the filament leads from socket terminals *2* and *7*.

d. Remove all leads from terminals *9, 10, 11, 12, 13* and *14* except those on terminals *9* and *10* which go to the power pack and potentiometer.

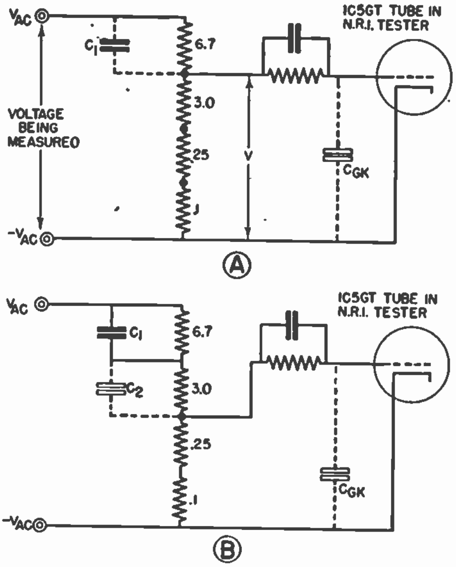


FIG. 14. Simplified schematic circuit diagram of the N.R.I. Tester as it is when used for a.c. voltage measurements on the *3 × V* range (*A*) and on the *30 × V* range (*B*).

e. Remove all leads from potentiometer terminal *17*. Finally, remove surplus solder from all terminals and leads. The only leads now left underneath the chassis should be the four power supply leads and the one on terminals *9* and *16*.

f. Place before you the following additional parts:

Three-winding s.g. (signal generator) coil (Part *5-7*).

370-mmfd. trimmer condenser (Part *5-9A*).

.001-mfd. paper condenser (Part *5-10*).

.01-mfd. paper condenser (Part *5-11*).
Machine screws and nuts (Parts *5-16A* and *5-16B*).
Grid clip with attached lead.
Four 40,000-ohm resistors (Parts *3-6A*, *3-6B*, *3-6C* and *3-6D*).
1000-ohm resistor (Part *5-18*).

Step 2. To assemble an r.f. oscillator according to the schematic circuit diagram shown in Fig. 15, carry out the following instructions for mounting and wiring the parts, using the semi-pictorial diagrams in Figs. *16* and *17* as your guides.

✓*a.* Mount the s.g. coil (signal generator coil) on top of the chassis by removing one nut from each of its mounting screws, inserting the screws through holes *hh* and *ii* in such a way that the *yellow* and *gray* terminals will be above holes *i* and *j*, as shown in Fig. *16*, then replace the nuts on the screws underneath the chassis and tighten with pliers. (Colored dots of paint on the coil terminals serve to identify these terminals.)

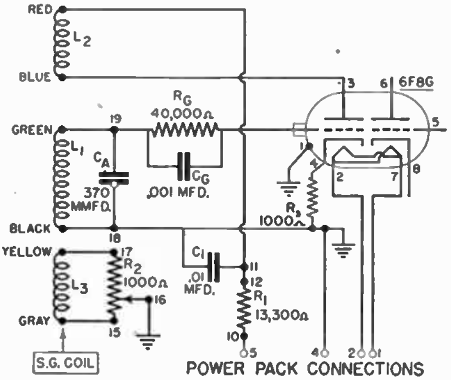


FIG. 15. Schematic circuit diagram of the r.f. oscillator which you assemble as a part of Experiment 44. R_1 is made up of three 40,000-ohm resistors connected in parallel between terminals *10* and *12*.

✓*b.* Mount the 370-mmfd. trimmer condenser C_A underneath the chassis by pushing a binder-head machine screw through hole *dd* from the top of the chassis, placing the trimmer condenser over this screw underneath the chassis exactly as shown in Fig. *17*, then placing a nut on the screw and tightening with pliers and screwdriver. Place the notation C_A near this condenser both above and below the chassis, and place the numbers *18* and *19* on the bottom of the chassis near the condenser terminals with metal-marking crayon, as shown in Figs. *16* and *17*.

✓*c.* With the chassis upside down, connect socket terminal *1* to terminal *9* with a suitable length of red hook-up wire.

From now on, you are expected to use your own judgment as to the best time for soldering each joint. Use the semi-pictorial wiring diagram as your guide; if more than one wire is shown on a particular terminal, do not solder the terminal until you have placed on it all of the wires which are called for on the diagram.

✓*d.* Connect a 1000-ohm resistor between socket terminals *1* and *4*.

✓*e.* Cut a 6-inch length of red hook-up wire, connect one end to socket terminal *3*, bring the wire around the potentiometer and up through chassis hole *f* as indicated in Fig. *17*, and

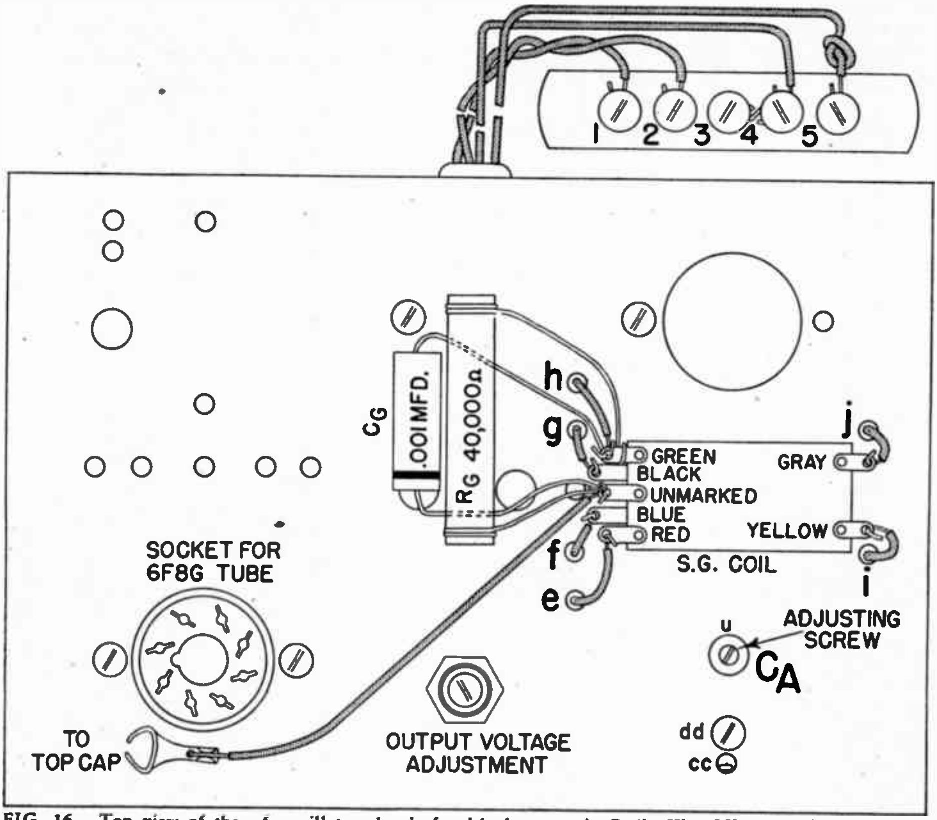


FIG. 16. Top view of the r.f. oscillator chassis furnished to you in Radio Kit 5RK-1, showing parts and connections as they should be made for the r.f. oscillator which you assemble in Experiment 44.

connect the other end of this wire to the *blue* terminal lug of the s.g. coil.

f. Connect terminal *11* to the *red* terminal lug of the s.g. coil, bringing the wire through chassis hole *e*.

g. Connect terminal *14* to the *black* terminal lug of the s.g. coil, bringing the wire through hole *g*.

h. Connect trimmer condenser terminal *19* to the *green* lug of the s.g. coil, bringing the wire through hole *h*.

i. Connect trimmer condenser terminal *18* to terminal *14* with hook-up wire.

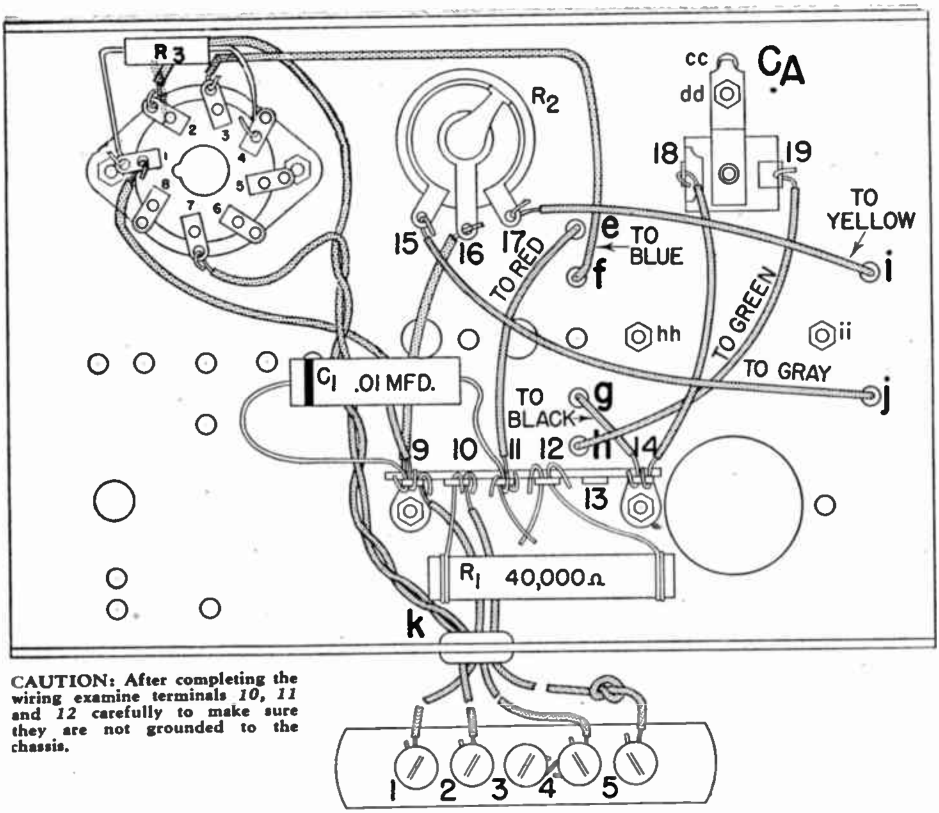
j. Connect the .01-mfd. condenser between terminals *9* and *11*, with the outside foil lead of the condenser going to terminal *9*.

k. Connect potentiometer terminal *15* to the *gray* lug of the s.g. coil, bringing the hook-up wire through chassis hole *j*.

l. Connect potentiometer terminal *17* to the *yellow* lug of the s.g. coil, bringing the hook-up wire through hole *i*.

m. Connect a 40,000-ohm resistor between terminals *10* and *12* by means of temporary soldered hook joints, arranging the resistor so that it has the same position as resistor R_1 in Fig. *17*.

Cut two 1-inch lengths of bare hook-up wire, connect one of these to terminal *12* by means of a temporary soldered hook joint, connect the other 1-inch length to terminal *11* by means of a temporary soldered hook joint,



CAUTION: After completing the wiring examine terminals *10, 11* and *12* carefully to make sure they are not grounded to the chassis.

FIG. 17. Bottom view of the oscillator chassis, showing all connections as they should be made for the r.f. oscillator which you assemble in Experiment 44. For the first measurement in this experiment, R_1 must be 13,300 ohms; this is obtained by connecting three 40,000-ohm resistors in parallel to terminals *10* and *12* in the manner shown in Fig. *18*.

then cross over the other ends of these two bare wires and solder them together by means of a lap joint, as indicated in Fig. *17*.

Now connect two other 40,000-ohm resistors in parallel with that already on terminals *10* and *12*, in the following manner:

Connect one of these 40,000-ohm resistors to the opposite sides of terminals *10* and *12* by means of temporary soldered lap joints, as shown in Fig. *18*. Bend the leads of this resistor so that the resistor body is in contact with the body of the .01-mfd. condenser (this will not do any harm). Now take another 40,000-ohm resistor and connect it to the leads of the first resistor (R_1) with temporary soldered lap joints, after first folding the resistor leads inward as shown in Fig. *18*, so that the lap joints will be well away from terminals *10* and *12*.

n. Turn the chassis over, and connect the remaining 40,000-ohm resistor between the *green* lug and the *unmarked* extra lug on the s.g. coil. (This unmarked lug is provided as an anchor point, and is not connected to any of the coil windings).

o. Connect the .001-mfd. condenser between the *green* lug and the *unmarked* lug on the s.g. coil, so that this condenser is in parallel with the 40,000-ohm resistor.

✓ *p*. Locate the length of hook-up wire which has the grid clip attached to one end, connect it to the *unmarked* lug on the s.g. coil, insert the type 6F8G tube in its socket and place the grid clip on the top cap of this tube.

✓ *q*. You have now assembled the r.f. oscillator according to the schematic circuit diagram shown in Fig. *15*. Check all of your connections carefully against the semi-pictorial diagrams in Figs. *16* and *17*, then make connections to the power pack exactly as you did for the a.f. oscillator (twisted wires go to power pack output terminals *1* and *2*, knotted wire goes to *5*, and the other wire goes to *4*).

✓ *Step 3. To determine whether your r.f. oscillator is operating properly,* prepare the N.R.I. Tester for d.c. voltage measurements by setting the selector switch to *100* × *V* and plugging the probes into the V_{DC} jacks, then place the black clip on the *unmarked* s.g. coil terminal, and place the red clip on the *green* terminal.

Set trimmer condenser C_A for maximum capacity by inserting your screwdriver through chassis hole *u* from the top of the chassis and rotating the adjusting screw as far as it will go in a clockwise direction. This tightens the trimmer condenser plates. Now rotate the screwdriver 1½ turns in a counter-clockwise direction, so as to set your circuit to oscillate at about 900 kilocycles.

✓ Turn on the power pack, turn on the N.R.I. Tester, wait about one half a minute, then switch to the *30* × *V* range. If a deflection of the meter pointer is observed, you know that the oscillator is operating. With this test, you are merely measuring the d.c. voltage drop produced across the 40,000-ohm grid resistor by the flow of grid current.

✓ For an additional check of operation, turn off all apparatus, move the probes to the V_{AC} jacks, move the red clip to the *yellow* s.g. coil terminal, and attach the black clip to the chassis. Set the N.R.I. Tester to the *V* range, then turn on the power pack and the N.R.I. Tester. After about half a minute, you should note a deflection of the meter pointer if the potentiometer R_2 is approximately in a mid-position. Rotate the potentiometer on the oscillator chassis with your screwdriver to see how it controls the r.f. output voltage value, but do not attempt to read the meter or record any values during these preliminary tests.

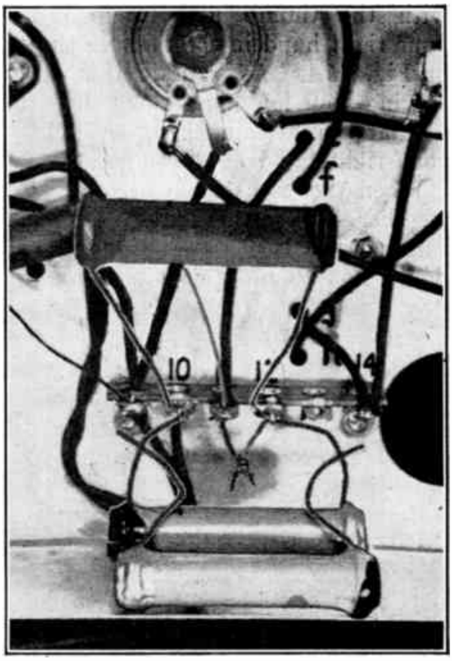


FIG. 18. Method of connecting three 40,000-ohm resistors in parallel to terminals *10* and *12* so as to secure a 13,300-ohm plate supply resistance.

Always turn off the power pack and the N.R.I. Tester when through with a test or measurement, even though instructions are not specifically given.

Step 4. To adapt the N.R.I. Tester for r.f. measurements, first secure the two 8-inch lengths of insulated wire which are supplied in Radio Kit 5RK as Part *5-17*, remove the insulation for about ⅜ inch from one end of each wire, and tin the exposed wire. Hold the bare ends side by side with the thumb and forefinger of your left hand, and twist the wires together with the thumb and forefinger of your right hand in the manner shown in Fig. *19A*. As you do this, keep moving your left hand along the wire so that it is within about an inch of your right hand at all times.

When the wires have been twisted together, pull the ends of the twisted length with two pairs of pliers as shown in Fig. *19B* to make the wires stay twisted. Connect the twisted wires to terminals *21* and *22* of the selector switch in your N.R.I. Tester with soldered lap joints, as shown in Fig. *19C*. Allow the twisted wires to extend beyond the chassis for the time being.

Remove the test probes from the N.R.I. Tester and check the calibration in the usual manner, then replace the test probes in the V_{AC} jacks. Leave the test clips still connected to the *yellow* s.g. coil terminal and the chassis. Set the selector switch at *V*, turn on the power pack and the N.R.I. Tester, wait about half a minute for tubes to warm up, then adjust the potentiometer (R_2) on the oscillator chassis until the meter reading on the *AC* scale is exactly 4.5 (corresponding to an r.f. voltage of 4.5 volts).

Without turning off the apparatus or changing any adjustments, move the selector switch to the $3 \times V$ setting and note the meter reading on the *AC* scale. If the reading is higher than 1.5, cut off with side-cutting pliers about half an inch from the end of the twisted pair of wires without turning off the apparatus, then take your hands away from the wires and tap the meter lightly to overcome bearing friction. If the reading is still higher than 1.5, cut another half-inch from the twisted wires and again tap the meter to get the reading accurately. Continue shortening these wires until the meter reads 1.5 on the *AC* scale. It should not be necessary to cut more than about 2 inches of wire at the most to secure this calibration, and sometimes it may not be necessary to cut any wire.

Switch to the *V* range to make sure that the reading is still exactly 4.5 volts on the *AC* scale for this range. You have now made a calibration which insures that readings on the $3 \times V$ range will be exactly three times the readings on the *V* range at radio frequencies.

Arrange the remaining length of twisted wire in a neat loop, as shown in Fig. *19D*, being sure that the exposed bare ends of the wire are not touching each other or any nearby parts. This twisted wire is to be left in this position permanently, for it serves to correct r.f. measurements and does not interfere with other types of measurements.

Step 5. To measure voltage and current values in your r.f. oscillator circuit when a plate supply resistance value of 13,300 ohms is employed and there is no r.f. load, remove the lead which runs between potentiometer terminal *17* and the *yellow* terminal of the s.g. coil, then remove the lead which runs between potentiometer terminal *15* and the *gray* terminal of the s.g. coil.

Now measure the d.c. plate voltage of the oscillator tube with the N.R.I. Tester by placing the red clip on the *red* s.g. coil terminal and placing

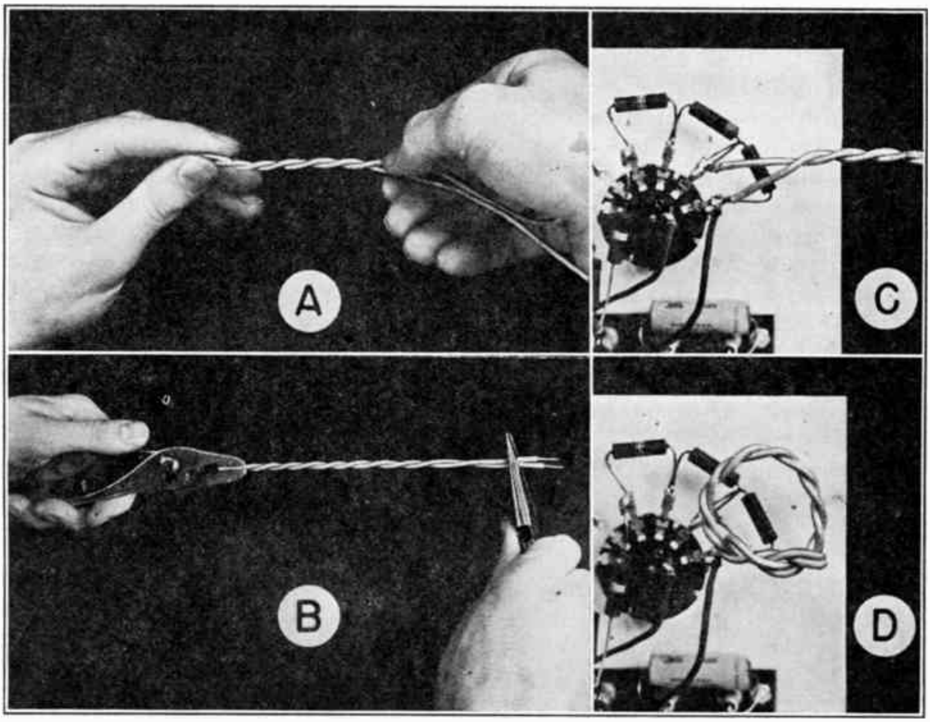


FIG. 19. **Steps in connecting to terminals *21* and *22* of the N.R.I. Tester an additional capacity which consists of two insulated leads twisted together.**

the black clip on the chassis, after preparing the tester for d.c. voltage measurements. Set the selector switch at *100* × *V*, turn on the power pack, turn on the N.R.I. Tester, wait about half a minute for the tubes to warm up, read the meter on the *DC* scale, multiply the reading by 100, and record your result in Table *44* as the d.c. plate voltage for a 13,300-ohm plate supply resistor. Turn off the N.R.I. Tester and the power pack. (The measurement is made to the plate supply end of the coil instead of to the plate, so as to prevent the capacity of the tester from affecting operation of the oscillator.)

Next, measure the d.c. C bias voltage value which is developed across the 40,000-ohm grid resistor by the flow of rectified grid current through this resistor. To make this measurement, place the test clips across this 40,000-ohm resistor which is above the chassis, with the red clip going to that resistor terminal which is on the *green* terminal of the s.g. coil. With the selector switch still at *100* × *V*, turn on the power pack and the N.R.I. Tester, wait about half a minute, then switch to the lowest range which does not overload the meter, read the meter, and record your result in Table *44* as the C bias voltage in volts for a 13,300-ohm plate supply resistance. Turn off the N.R.I. Tester and the power pack.

Do not touch the chassis or panel of the N.R.I. Tester when measuring the C bias voltage; the capacity of your body would have the effect of grounding the grid of the oscillator tube, thereby upsetting circuit conditions and giving erroneous voltage readings. Keep the test leads away from the s.g. coil as much as possible.

Now measure the r.f. voltage existing across the tank circuit (the tank circuit in this oscillator is made up of the 370-mmfd. trimmer condenser and the s.g. coil which has its terminal lugs marked *green* and *black*). This can be done simply by leaving the red clip on the *green* s.g. coil terminal, moving the black clip to the chassis, moving the red probe to the left-hand V_{AC} jack, setting the selector switch back to *100* × *V*, then turning on the power pack and the N.R.I. Tester. After waiting half a minute, switch to the *30* × *V* range, read the meter, multiply the reading by 30, and record your result in Table *44* as the r.f. tank circuit voltage for a 13,300-ohm plate supply resistor. Turn off the N.R.I. Tester and the power pack.

Finally, measure the d.c. plate current of the oscillator tube in the following manner. Prepare the N.R.I. Tester for direct current measurements by moving the test probes to the *I* jacks and setting the selector switch to *10* × *I*. Open the plate circuit between terminals *11* and *12* under the oscillator chassis by unsoldering the lap joint between the two bare 1-inch lengths of wire on these terminals, place the red clip on the bare wire going to terminal *12*, and place the black clip on the bare wire going to terminal *11*. After making sure that the clips do not touch other terminals, turn on the power pack and the N.R.I. Tester while leaving the oscillator chassis upside down, wait about half a minute, then read the meter on the *DC* scale, multiply the reading by 10, and record your result in Table *44* as the d.c. plate current in

OPERATING INSTRUCTING FOR N.R.I. TESTER

R.F. VOLTAGE MEASUREMENTS

1. **Check the calibration of the N.R.I. Tester in the usual manner, as instructed in previous manuals. Be sure the U-shaped jumper is in the *PHONE* jacks during calibration. Tap the meter lightly with your finger during calibration to minimize bearing friction.**
   Special Note: These instructions assume that you have already added the twisted wire to the N.R.I. Tester, according to the instructions given in Step 2 of Experiment 44.
2. **Place the red probe in the left-hand V_{AC} jack, and place the black probe in the —V_{AC} jack.**
3. **Start with the selector switch set at the *30* × *V* range. Switch to a lower range only after all tubes in the circuit have warmed up and reached normal operating conditions. The *100* × *V* range is never used for r.f. measurements.**
   Choose for your final reading the range which gives the *highest result in volts* (not the highest scale reading).
   Do not under any condition use a scale reading higher than *4.5* on the *AC* scale; switch to the next higher range whenever the pointer is above *4.5* on this scale. This is necessary because scale readings above *4.5* are inaccurate for r.f. measurements.
   ***Important:* Whenever you obtain an off-scale reading through accident or otherwise, be sure to correct the calibration immediately by moving the calibrating clip temporarily to the —4½C terminal, then returning the clip to the —9C terminal.**
4. **Read r.f. voltages on the *AC* scale in exactly the same manner as for a.c. measurements.**
5. **If a scale reading above *4.5* is obtained with the *3* × *V* range, you can: *1.* Estimate the value as being a few volts higher than 13.5 volts; *2.* Switch to the *30* × *V* range and read as best you can, although it will be difficult to secure an accurate reading because the pointer is below 1 on the scale. (The 10-megohm resistor cannot be used as a multiplier for doubling a voltage range during r.f. measurements, because we now have a capacity voltage divider.)**

STEP	PLATE SUPPLY RESISTANCE IN OHMS	D.C. PLATE VOLTAGE IN VOLTS		C BIAS VOLTAGE IN VOLTS		R.F. TANK CIRCUIT VOLTAGE IN VOLTS		D.C. PLATE CURRENT IN MA	
		YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.
5	13,300	200	160	45	66	97	72	10	15
6	20,000	160	130	37	48	63	54	7.5	10
7	40,000	97	110	28	30	20	30	4	5

10-2/L

TABLE 44. Record your results here for Experiment 44.

ma. for a 13,300-ohm plate supply resistor. Turn off the N.R.I. Tester and power pack.

Warning: **During this current measurement, the tester chassis is at a high d.c. potential with respect to the other chassis units and to ground, because the current measurement is being made at a point which is highly positive with respect to ground. Therefore, do not touch the oscillator chassis, the power pack chassis, or any other grounded object while turning on, turning off or adjusting the tester for this and similar *current* measurements.**

✓ *Step 6. To measure voltage and current values in your r.f. oscillator when a plate supply resistance value of 20,000 ohms is used,* first remove the last 40,000-ohm resistor which you connected to terminals *10* and *12* (this leaves only two 40,000-ohm resistors connected to terminals *10* and *12*). Since the N.R.I. Tester and its clips are still set for d.c. plate current measurements, make this measurement first exactly as instructed in Step 5, and record your result in the right-hand column of Table *44* as the d.c. plate current in ma. for a 20,000-ohm plate supply resistance.

Remove the test clips and solder together again the two bare leads on terminals *11* and *12*. Measure the *d.c. voltage* now between the *red* s.g. coil terminal and the chassis exactly as instructed in Step 5, and record your result in Table *44* as the d.c. plate voltage in volts for a 20,000-ohm plate supply resistor.

Measure the d.c. voltage drop across the 40,000-ohm grid resistor exactly as instructed in Step 5, and record your result in Table *44* as the C bias voltage in volts for a 20,000-ohm plate supply resistor.

Measure the r.f. voltage across the tank circuit as instructed in Step 5, and record your result in Table *44* as the r.f. tank circuit voltage in volts for a 20,000-ohm plate supply resistor.

Step 7. To measure voltage and current values in your r.f. oscillator circuit when a plate supply resistor value of 40,000 ohms is used, first unsolder and remove one of the two 40,000-ohm resistors which are still connected to terminals *10* and *12*. This leaves only a single 40,000-ohm resistor in the plate supply circuit of the oscillator.

Measure the d.c. voltage between the *red* s.g. coil terminal and the chassis, and record your result in Table *44* as the d.c. plate voltage in volts for a 40,000-ohm plate supply resistor. If necessary, switch to the *30* × *V* range to obtain a more accurate reading.

Measure the d.c. voltage across the 40,000-ohm grid resistor and record your result in Table *44* as the C bias voltage in volts for a 40,000-ohm plate supply resistor. Switch to the lowest range which does not overload the meter, to obtain as accurate a reading as possible for this measurement.

Measure the r.f. voltage between the *green* s.g. coil terminal and the chassis, and record your result in Table *44* as the r.f. tank circuit voltage in volts for a 40,000-ohm plate supply resistor. You will probably have to use the *30* × *V* range for this measurement.

Measure the d.c. plate current by unsoldering the joint between the two bare wires on terminals *11* and *12*, placing the red clip on the wire going to *12*, placing the black clip on the wire going to *11*, then measuring the current as instructed in Step 5 and recording your result in Table *44* as the d.c. plate current in ma. for a 40,000-ohm plate supply resistor. Be sure to turn off the N.R.I. Tester and the power pack after completing this final measurement.

Discussion: The N.R.I. values in Table *44* indicate definitely that as the d.c. plate voltage is lowered (by increasing the value of the plate supply resistance), the C bias voltage, the r.f. tank circuit voltage and the d.c. plate current will all drop correspondingly. Your value should show this same drop with d.c. plate voltage even though the values themselves may be entirely different from corresponding N.R.I. values.

Oscillator Circuit Theory. When a vacuum tube oscillator like that which you set up in this experiment reaches normal operating conditions, the grid is being driven sufficiently positive to produce a grid current flow and this develops a definite C bias voltage across the grid resistor. The a.c. voltage which is developed across the tank circuit makes the grid swing alternately positive and negative with respect to the fixed C bias voltage value.

If the oscillator tube had an E_G-I_P characteristic curve like that shown in Fig. *20A*, the a.c. tank voltage e_g might swing sufficiently positive to place the C bias voltage E_C beyond cut-off, as indicated in the diagram. Under this condition, plate current can flow only when e_g is swinging more positive than the cut-off bias value, and the plate current i_p becomes a pulse having an operating angle less than 180° (so that plate current flows for less than half of each grid voltage cycle).

The plate current pulse i_p in Fig. *20A* represents the power required to maintain oscillation, for it is the power in this plate current pulse which is fed back into the tank circuit for the purpose of setting this resonant circuit into natural oscillation.

The area of the plate current pulse i_p (the shaded portion in Fig. *20A*), when considered as a graph, is proportional to the amount of power drawn by the oscillator from its d.c. supply source. The greater the area of this pulse, the more power the oscillator will be able to deliver. Theoretically, the area of this current pulse can be increased by increasing the peak value of the pulse, by increasing the operating angle, and by making the pulse flatter at the top so that its sides will be steeper; all three of these factors will thus tend to increase the amount of power which the oscillator is capable of delivering.

The d.c. power drawn by the oscillator has a number of functions to perform. In addition to supplying the r.f. power which is drawn from the oscillator by its load circuit or by associated equipment, this d.c. power must overcome the losses in the tank circuit, the power dissipated in the grid resistor, the power dissipated in the grid-cathode resistance of the oscillator tube, the power dissipated in the plate-cathode resistance of the oscillator tube, and incidental circuit losses such as that due to the resistance of the wiring.

Now let us consider how the a.c. tank voltage e_g is maintained at a definite level for a given set of operating voltages. Suppose there is a tendency for this a.c. tank voltage to *increase;* this makes the positive pulse of e_g swing more positive, so that grid current increases and the voltage drop E_C across the grid resistor increases correspondingly. This increased negative C bias moves the operating point further beyond cut-off, so that the operating angle of the plate current pulse i_p is reduced even though the peak value of this pulse may tend to increase. With the area of the current pulse reduced in this manner, less power is available for oscillation, and consequently, a braking action occurs which makes the a.c. tank voltage return to its normal value.

If the a.c. tank voltage tends to *drop*, the C bias voltage decreases, making the operating angle of the plate current pulse greater. More power is then drawn from the d.c. supply source, making the a.c. tank voltage return to its normal value at which the d.c. power drawn by the oscillator is just enough to take care of oscillator circuit losses and the r.f. power being drawn from the oscillator.

The plate supply resistance changes made in this experiment change the d.c. plate voltage on the oscillator tube, so let us consider how the d.c. plate voltage changes can affect the C bias voltage, the r.f. tank voltage and the average value of the plate current pulse i_p.

First of all, we must realize that increasing the d.c. plate voltage gives a different E_G-I_P curve for the oscillator tube, as shown in Fig. *20B*. The cut-off bias voltage value is now more negative than before, and the plate current for any grid voltage value more positive than cut-off is much higher than before. Since the a.c. tank voltage must still swing the grid positive in order to produce the automatic C bias voltage required as a condition for oscillation, the a.c. tank voltage becomes much higher for the higher plate voltage value. Furthermore, the area of the plate current pulse i_p becomes larger, and its average d.c. value as measured by the N.R.I. Tester becomes correspondingly higher than before. Finally, since the fixed C bias must be more negative than cut-off under this condition, the C bias voltage developed across the grid resistor is also higher than before. The measurements which you made for this experiment are thus all confirmed by this theoretical analysis.

One fact which is worth remember-

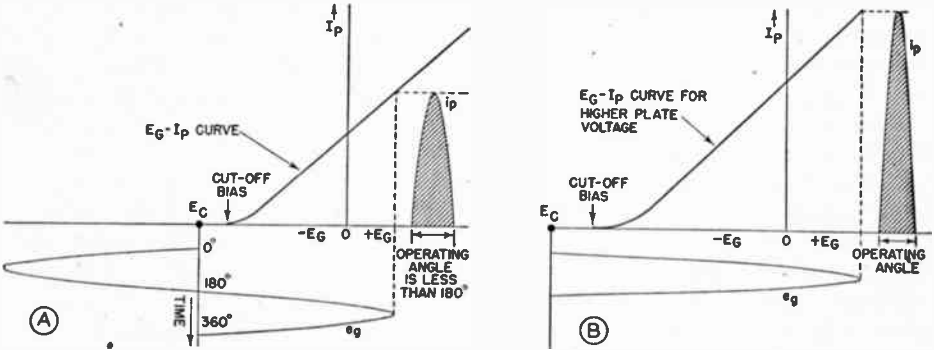


FIG. 20. These characteristic curves for a triode vacuum tube will help you to understand how your r.f. oscillator functions.

ing in connection with this oscillator experiment is that an increase in the a.c. tank voltage is always accompanied by an increase in the C bias voltage developed across the grid resistor. From a practical standpoint, this means that you can tell if the oscillator is working and determine how the r.f. tank voltage value is varying simply by measurng the d.c. voltage across the grid resistor with an ordinary high-sensitivity d.c. voltmeter such as the N.R.I. Tester.

The purpose of the 1000-ohm resistor in the cathode circuit is to introduce a sufficient amount of degeneration to stabilize the circuit. The voltage drop across this resistor acts as a variable bias that opposes changes in the grid circuit. This resistor must not be by-passed.

Instructions for Report Statement No. 44. On the basis of the measurements you have already made, you should now be able to predict what happens to the oscillator circuit values when the d.c. plate voltage is reduced still more by using an 80,000-ohm plate supply resistance. You can verify your prediction very easily, simply by inserting the 80,000-ohm resistance in the plate circuit and measuring the C bias voltage.

For this report statement, break the connection between terminals *11* and *12*, then connect another 40,000-ohm resistor between terminals *11* and *12*, so that you now have two 40,000-ohm resistors in series between terminals *10* and *11* to give an 80,000-ohm plate supply resistance.

Turn the chassis over, and measure the d.c. voltage across the 40,000-ohm resistor to secure the C bias voltage for an 80,000-ohm plate supply resistance. Compare this measured C bias voltage value with that which you recorded for a 40,000-ohm plate supply resistance in Table *44*, then answer Report Statement No. 44.

Be sure that you turn off the N.R.I. Tester and the power pack, and remove the test leads both from the N.R.I. Tester and the oscillator after making the final measurement for Experiment 44.

EXPERIMENT 45

***Purpose:* To show that there is a minimum value of feed-back coupling below which oscillation cannot be maintained in an r.f. oscillator circuit; to show that increasing the feed-back coupling beyond the minimum value increases the r.f. tank voltage, the C bias voltage and the d.c. plate current of the oscillator tube.**

Preliminary Discussion: The signal generator coil which you use in your r.f. oscillator has two windings in addition to the main tuning coil across which the 370-mmfd. trimmer condenser is connected. One of these additional windings (the one at the end of the coil form) has twenty-two turns, while the other winding (near the center of the coil form) has sixteen turns. Connecting these two coils in series gives a total of thirty-eight turns, while connecting them in opposition gives six turns. Thus, by varying coil connections we can secure four different values of feed-back coupling: six turns; sixteen turns; twenty-two turns; thirty-eight turns.

Step 1. To make oscillator circuit measurements with twenty-two turns of feed-back coupling, first insert a 40,000-ohm plate supply resistance by removing the 40,000-ohm resistor which you connected between terminals *11* and *12* in the previous experiment, then connecting together terminals *11* and *12* by means of the short bare lengths of wire so that a single 40,000-ohm resistor is connected between terminals *10* and *12*.

✓ Measure the d.c. voltage between

STEP	FEED-BACK COUPLING TURNS	D.C. PLATE VOLTAGE IN VOLTS		C BIAS VOLTAGE IN VOLTS		R.F. TANK VOLTAGE IN VOLTS		D.C. PLATE CURRENT IN MA.	
		YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.
2	6	150	150	0	0	4.8	0	5	5
4	16	140	110	25	27	40	30	7	7
1	22	140	110	30	30	46	33	7	7
3	38	125	84	45	66	75	69	9	9

TABLE 45. Record your results here for Experiment 45.

the *red* s.g. coil terminal and the chassis, and record your result in Table *45* as the d.c. plate voltage when the feed-back coupling is twenty-two turns. Note that your readings for this step are to be recorded in the third horizontal line of Table *45;* this is done so that you can secure the various coupling arrangements in the easiest possible manner and yet still have your values arranged in the order of increasing coupling. This procedure is common practice in laboratory work.

Measure the d.c. voltage across the 40,000-ohm resistor (red clip on *green* terminal) and record your result in Table *45* as the C bias voltage in volts for a feed-back coupling of twenty-two turns.

Turn the chassis on its side, measure the r.f. voltage across the 370-mmfd. trimmer condenser with the *30* × *V* range (black clip on grounded lead, which goes to terminal *14*) and record your result in Table *45* as the r.f. tank circuit voltage in volts for a feed-back coupling of twenty-two turns.

Measure the current flowing between terminals *11* and *12* by breaking the connections between these terminals and inserting your measuring instrument, then record your result in Table *45* as the d.c. plate current in ma. for a feed-back coupling of twenty-two turns. Be sure to connect terminals *11* and *12* together again after completing this current measurement.

Step 2. To make oscillator circuit measurements for a feed-back coupling of six turns, change the feed-back coupling to six turns in the following manner: unsolder the lead from the *blue* s.g. coil terminal, connect a 3-inch length of hook-up wire to this *lead* by means of a temporary soldered hook joint, and connect this wire to the *yellow* terminal of the s.g. coil. Now connect the *gray* and *blue* terminals of the s.g. coil together with a suitable length of hook-up wire.

Measure the d.c. voltage between the *red* s.g. coil terminal and the chassis, and record your result in Table *45* as the d.c. plate voltage in volts for a feed-back coupling of six turns. Note that all readings for this step are to go in the first horizontal line of Table *45*.

Measure the d.c. voltage across the 40,000-ohm resistor, and record your result in Table *45* as the C bias voltage in volts for a feed-back coupling of six turns.

Measure the r.f. voltage across the 370-mmfd. trimmer condenser by using the *V* range of the N.R.I. Tester, and record your result in Table *45* as the r.f. tank voltage in volts for a feed-back coupling of six turns.

Measure the direct current flowing between terminals *11* and *12* and record your result in Table *45* as the d.c. plate current in ma. for a feed-back coupling of six turns.

Step 3. To make oscillator circuit measurements for a feed-back coupling of thirty-eight turns, first change the feed-back coupling to thirty-eight turns by reversing the connections which you made in the previous step to the *gray* and *yellow* terminals of the s.g. coil. In other words, remove from the *gray* terminal the wire which goes to the *blue* terminal, and place this instead on the *yellow* terminal. Remove from the *yellow* terminal the wire which goes through chassis hole *f*, and connect this wire instead to the *gray* terminal.

Measure the d.c. voltage between the *red* s.g. terminal and the chassis and record your result in Table *45* as the d.c. plate voltage in volts for a feed-back coupling of thirty-eight turns. Note that all readings for this step go on the last horizontal line of Table *45*.

Measure the d.c. voltage across the 40,000-ohm grid resistor, and record your result in Table *45* as the C bias voltage in volts for a feed-back coupling of thirty-eight turns.

Measure the r.f. voltage across the 370-mmfd. trimmer condenser, using the *30* × *V* range of the N.R.I. Tester, and record your result in Table *45* as the r.f. tank voltage in volts for a feed-back coupling of thirty-eight turns.

Measure the direct current flowing between terminals *11* and *12*, and record your result in Table *45* as the d.c. plate current in ma. for a feed-back couping of thirty-eight turns.

Step 4. To make oscillator circuit measurements for a feed-back coupling of sixteen turns, first unsolder the lead which is on the *blue* lug, unsolder the lead which is on the *red* lug, and connect these two unsoldered leads together by means of a temporary soldered hook joint so as to secure a feed-back coupling of sixteen turns.

Measure the d.c. voltage between the chassis and the soldered joint which you just made, and record your result in Table *45* as the d.c. plate voltage in volts for a feed-back coupling of sixteen turns. Note that your results for this step go on the second horizontal line of Table *45*.

Measure the d.c. voltage across the 40,000-ohm grid resistor, and record your result in Table *45* as the C bias voltage in volts for a feed-back coupling of sixteen turns.

Measure the r.f. voltage across the 370-mmfd. trimmer condenser, and record your result in Table *45* as the r.f. tank voltage in volts for a feed-back coupling of sixteen turns. Use the *3* × *V* range if the pointer stays below 4.5 on the *AC* scale; otherwise, use the *30* × *V* range for this measurement.

Measure the direct current flowing between terminals *11* and *12*, and record your result in Table *45* as the d.c. plate current in ma. for a feed-back coupling of sixteen turns.

Discussion: An analysis of the N.R.I. values obtained for this experiment will serve as a guide for you in analyzing your own results.

First of all, the zero C bias and zero r.f. tank voltage values obtained for a feed-back coupling of six turns indicate that this lowest number of turns is not sufficient to produce oscillation. The d.c. plate current value of 5 ma. obtained with this six-turn coupling simply corresponds to the plate current for zero C bias and a d.c. plate voltage of 150 volts. Any disturbances which might exist in the plate circuit cannot feed a sufficiently strong pulse of energy into the tank circuit to set that circuit into natural oscillation and keep it oscillating.

Oscillation could be secured even with only six turns of coupling, however, if the plate voltage were increased. For example, we increased the plate voltage in the N.R.I. laboratory by shorting out the 40,000-ohm plate load resistor; this made the d.c. plate voltage go up to 370 volts, and we then measured an r.f. tank voltage of 7.8 volts, proving that the circuit was oscillating. The d.c. plate current under this condition was 30 ma., indicating that when coupling is weak both the d.c. plate voltage and the d.c. plate current must be high in order to secure even a low value of r.f. tank voltage. It is not advisable for you to try this experiment yourself, since the measurement must be made quickly in order to prevent damage to the 6F8G tube by the high plate current which flows when the plate load resistor is shorted.

A feed-back coupling of sixteen turns was obviously sufficient to produce oscillation, as the r.f. tank voltage value for this coupling was 30 volts. Note that as the feed-back coupling is increased, both the r.f. tank voltage and the C bias voltage increase. Increasing the coupling raises the mutual inductance existing between the coils, so that more of the a.c. plate circuit energy can be transferred through this mutual inductance to the tank circuit. With more energy fed into it, the tank circuit develops a greater r.f. voltage, and this in turn sends a higher rectified grid current through the grid resistor to produce across this resistor a higher C bias voltage value.

Although N.R.I. values are recorded for d.c. plate current, it must be admitted that these were obtained under extremely difficult conditions and are therefore far from accurate. To obtain these values, it was necessary to use the $10 \times I$ range of the N.R.I. Tester, and this range gave readings so close to zero that variations of 1 or 2 milliamperes could hardly be detected.

Computations: We do not have to rely upon measured plate current values, however, for we can readily compute the true plate current through its relationship with the d.c. plate voltage. Since our measured values indicate that the d.c. plate current is not changing appreciably, we can safely assume that the power pack d.c. output voltage remains constant throughout the experiment.

The computations require measurement of this power pack d.c. output voltage, it being 430 volts for the N.R.I. values. With a 40,000-ohm plate supply resistor being used to limit the d.c. plate voltage acting upon the tube, the difference between the d.c. supply voltage and the d.c. plate voltage will be the d.c. voltage drop across the plate supply resistor. This voltage drop divided by the 40,000-ohm resistance value then gives us the true d.c. plate current value.

For example, with a coupling of twenty-two turns in Step 1, the voltage drop across the resistor would be 430 volts minus 110 volts, which is 320 volts; dividing 320 volts by 40,000 ohms gives 8 ma. Just as we expected, this true computed value is somewhat different from the measured value of 7 ma. Computations for the other three experiments would show just about this same discrepancy between measured N.R.I. values and true current values.

It is not necessary for you to make these calculations of plate current, however, for in this experiment we are interested simply in knowing whether the plate current goes up or down, and the measured plate voltage values give this information. The lower the plate current, the lower will be the voltage drop produced across the 40,000-ohm plate supply resistor by this plate current, and the higher will be the resulting d.c. plate voltage. Thus, for a high value of plate current, the drop across the resistor will be high, giving only a low d.c. voltage for the plate.

Examination of the N.R.I. d.c. plate voltage values shows that the d.c. plate voltage is lowest for thirty-eight turns of coupling; the d.c. plate current must therefore be the highest for this coupling. Furthermore, the d.c. plate voltage is the highest for six turns, and therefore the d.c. plate current must be lowest for this coupling.

In any oscillator circuit, the d.c. plate voltage multiplied by the d.c. plate current gives the oscillator input power. This holds true for your oscillator circuit as well; we can neglect the power lost in the plate supply resistor because in a practical high-efficiency oscillator circuit the power pack would be designed to supply exactly the correct voltage, and consequently no voltage-reducing plate supply resistor would be employed. The power required to heat the filament is likewise neglected, as it remains the same for a particular tube regardless of how that tube is employed.

Optimum coupling occurs when the maximum r.f. tank voltage per watt of oscillator power input is obtained. Although we cannot draw any definite conclusion as to optimum coupling from the values obtained in this experiment, additional measurements in the N.R.I. laboratory indicated that about thirty turns gave optimum coupling. The number of turns which gives optimum coupling varies with the d.c. plate voltage, the load, the d.c. grid voltage, etc. In an oscillator circuit where some means is provided for varying the coupling, it will be found that for a given plate voltage and fixed circuit constants, optimum coupling will exist when the ratio of r.f. tank voltage to d.c. plate current is a maximum.

It is possible to increase the coupling to the point where the oscillator operates intermittently even though normal grid leak values are used. Technically, we say that the oscillator *blocks* due to over-coupling. This over-coupling tends to produce such a high r.f. tank voltage that it makes the grid drive the oscillator tube up to plate current saturation, with the tank circuit capable of supplying still more excitation. This causes a large negative C bias voltage, making the operating angle too small to supply the energy required for oscillation, with the result that oscillation stops.

It takes a number of cycles before this condition takes place, so the circuit will oscillate normally for a short time before it stops or blocks. When the C bias is reduced by normal leakage through the circuit, the oscillator will start again and the cycle will repeat itself. With the apparatus available for these experiments, we are not able to produce sufficient coupling to give intermittent blocking while using the low grid resistance value which we have in this particular circuit. This blocking action will be demonstrated with a different circuit in the next experiment.

When two coils are connected in series aiding as is done in Step 3, the total effective number of turns is the sum of the individual turns. The current then flows in the same direction through both of the coils. When two coils are connected in series bucking, so that current flows in different directions through the two coils, the effective number of turns is the difference between those on the individual coils; this is how we secure six turns in Step 2.

Instructions for Report Statement No. 45. To determine the effect which reversal of feed-back coil connections has upon oscillation, replace the twenty-two-turn feed-back coil just as it was for Step 1 in this experiment, measure the C bias voltage again for this condition, then reverse the connections to the twenty-two-turn coil and measure the C bias voltage again.

Remember that the C bias voltage is produced by the r.f. tank voltage.

To accomplish all this, first remove entirely the short wire which connects the *gray* coil terminal to the lead coming out of hole *f*. Remove the short wire which connects the *yellow* coil terminal to the wire coming out of hole *e*. Connect to the *blue* coil terminal the wire which comes out of chassis hole *f*. Connect to the *red* coil terminal the wire which comes out of chassis hole *e*.

Measure the C bias voltage across the 40,000-ohm resistor now to make sure it is essentially the same as the value which you recorded for Step 1 in Table *45*, then reverse the connections to the *blue* and *red* coil terminals and again measure the C bias voltage. The lead coming out of hole *f* must be lengthened temporarily to make this reversal of connections possible. Now answer Report Statement No. 45.

EXPERIMENT 46

Purpose: **To show that increasing the ohmic value of the grid resistor in an oscillator circuit makes the automatic C bias voltage and the r.f. tank voltage both increase up to a certain point, after which the circuit begins blocking to produce intermittent oscillation resulting in audio frequency modulation of the r.f. signal; to show that when a load is placed on the tank circuit, the C bias voltage and the r.f. tank voltage will be lower but will increase in the same manner as before when the grid resistance value is increased.**

Step 1. To make the measurements called for in this experiment, first restore the original connections for the twenty-two-turn feed-back coil by reversing the positions of the leads on the *red* and *blue* s.g. coil terminals. (The lead from hole *f* should now go to the *blue* terminal, and the lead from hole *e* should go to the *red* terminal). The plate supply resistance is still 40,000 ohms.

In this experiment you will use five different values of grid resistance. For each value you will make three meter measurements and one phone test without any load connected across the tank circuit, then make three more meter measurements with a 40,000-ohm load connected across the tank circuit, so as to secure at one time all of the readings required for the two purposes of this experiment.

The six meter measurements and the phone test for each grid resistor value are to be made in the following manner:

Connect the grid resistor of the specified value between the *green* terminal and the *unmarked* terminal of the s.g. coil in place of the 40,000-ohm resistor previously on these terminals, while leaving the .001-mfd. condenser connected to these terminals just as before. The five grid resistor values which you are to use are 1,000 ohms, 40,000 ohms, 100,000 ohms, 140,000 ohms (obtained by placing the 40,000 and 100,000-ohm resistors in series between the *green* and *unmarked* terminals), and 10 megohms (Part 4-21). Make temporary soldered hook or lap joints being careful not to place excessive strain on the coil terminals while making a joint or removing leads.

With the grid resistor connected properly, first measure the d.c. voltage between the *red* s.g. coil terminal (red clip) and the chassis, and record your result in Table *46* as the d.c. plate voltage for the grid resistance being used, with no load on the tank circuit.

Measure the d.c. voltage between the leads of the grid resistor (red clip on *green* s.g. coil terminal) and record your result in Table *46* as C bias voltage for the grid resistance being used, with no load on the tank circuit.

Measure the r.f. voltage between the *green* s.g. coil terminal (red clip) and the chassis while using the voltage range specified at the top of the box in which the measurement is to be recorded in Table *46*, then record your result as the r.f. tank voltage in volts for the grid resistance being used, with no load on the tank circuit. Turn off all apparatus.

With the tester still connected as for the r.f. voltage measurement, remove the U-shaped jumper from the phone jacks and insert the metal tips of your headphone leads in these jacks. Set the selector switch at *V*. Listen for an audio tone after all apparatus is turned on again; if no tone is heard, record your result as *zero* for the frequency of oscillation with the grid resistance being used and with no load on the tank circuit. If a high-pitched tone is heard, corresponding to a high frequency, record your result as *HIGH;* if the tone is more of a rasping or buzzing sound, corresponding to a low frequency, record your result as *LOW*. Remove the phone tips and replace the U-shaped jumper in the phone jacks after making this test.

Connect a 40,000-ohm resistor temporarily between terminals *18* and *19* of trimmer condenser C_4 under the chassis, then repeat your d.c. plate voltage measurement, your C bias voltage measurement, and your r.f. tank voltage measurement, and record your results in the spaces provided for this purpose in Table *46* for the specified grid resistance value and a 40,000-ohm load on the tank circuit. When the three measurements have been completed, remove the 40,000-ohm resistor from terminals *18* and *19*, then change to the next grid resistance value and repeat the entire series of measurements again.

Discussion: An analysis of the N.R.I. values for this experiment shows that both the C bias voltage and the r.f. tank voltage go up as the ohmic value of the grid resistor is increased, regardless of whether or not there is a load across the tank circuit.

The larger the ohmic value of the grid resistor, the greater is the d.c. voltage developed across this resistor by a definite grid current value. The increased negative C bias resulting from increased grid current makes it necessary for the r.f. tank voltage to increase in order to swing the grid sufficiently positive to maintain oscillation. The combination of the more negative operating point and increased r.f. tank voltage means a smaller operating angle for the plate current, and consequently the average d.c. plate current drops. The resulting lower voltage drop across the plate resistance leaves more voltage for the tube itself, with the result that the d.c. plate voltage goes up. The N.R.I. values verify this analysis, for they show that the d.c. plate voltage goes up as the ohmic value of the grid resistor is increased.

The N.R.I. results in the *FREQUENCY* column of Table *46* indicate that intermittent oscillation occurs only when the grid resistance value is increased to 10 megohms, but you may also hear a tone in the headphone for the 140,000-ohm grid resistance value (blocking started in the N.R.I. laboratory at a grid resistance value only slightly higher than 140,000 ohms, and with some tubes and parts we actually did hear a *HIGH* frequency tone for this value).

The C bias voltage is high at high grid resistance values, but the r.f. tank voltage has not increased suffi-

GRID RESISTANCE IN OHMS	NO LOAD ON TANK CIRCUIT				40,000Ω LOAD ON TANK CIRCUIT		
	D.C. PLATE VOLTAGE IN VOLTS	C BIAS VOLTAGE IN VOLTS	R.F. TANK VOLTAGE IN VOLTS	FREQUENCY (PHONE TEST)	D.C. PLATE VOLTAGE IN VOLTS	C BIAS VOLTAGE IN VOLTS	R.F. TANK VOLTAGE IN VOLTS
1,000	75 100	1 1	4.8 3xV 4.6	0 0	78 120	.6 .5	4.5 V 4.5
40,000	117 120	30 30	36 30xV 40	0 0	135 125	15 3.5	14 3xV 14
100,000	150 140	54 34	63 30xV 60	0 0	160 155	21 17	18 30xV 18
140,000	160 150	64 38	54 30xV 60	0 0	180 165	24 14	21 30xV 30
10 MEG.	430 390	101 52	0 V 0	LOW LOW	430 340	72 42	0 V 3

TABLE 46. Record your results here for Experiment 46. In this particular table, the N.R.I. value is placed in the triangular area at one corner of the box in which you are to write your own value. The voltage range which you should use for each of the r.f. tank voltage measurements is indicated at the top of each of the boxes provided for these measurements.

ciently to offset this increase in negative bias. As a result, the grid is driven so far negative that for a few r.f. cycles no plate current is drawn, and oscillation ceases. The charge on the grid condenser then leaks off through the grid resistor, lowering the C bias and permitting the circuit to return to its normal oscillating condition. Oscillation again builds up the negative C bias, causing the circuit to block and repeat the entire cycle. This process continues indefinitely, and when it is within the audio frequency spectrum, a tone can be heard in the headphone. Actually, we have a self-modulating circuit in which the r.f. signal is modulated at an audio rate.

Commercial test oscillators often employ this self-modulating r.f. circuit so that a tone can be heard when the r.f. oscillator is connected to the input of a receiver.

When the grid resistance value is increased to the very high value of 10 megohms, oscillation occurs for such a short interval of time in between the blocking intervals that little or no r.f. voltage can be measured, even though it actually is present. Furthermore, increasing the grid resistance value increases the time required for the grid condenser to discharge and lower the C bias to the point where oscillation can continue, with the result that we hear a lower audio frequency note.

If the grid resistor value in megohms (140,000 ohms corresponds to .14 megohms) is multiplied by the capacity of the grid condenser in microfarads (.001 mfd.) we secure a value of .00014 seconds for the time constant of these two parts. This means that theoretically the circuit will block at intervals of about .00014 second. Dividing the number 1 by this time in seconds gives about 7,100 cycles as the frequency of blocking (1 ÷ .00014 = 7,100). The actual frequency will be somewhat lower than this theoretical value, however, for it takes a little time for the circuit to recover again after the blocking condition has cleared up.

With a 10-megohm grid resistor, the time constant becomes 10 × .001, or .01 second; this corresponds to 100 cycles, explaining why we hear a low-frequency note when the 10-megohm grid resistor is used. This is a buzz rather than a pure tone, because the modulation is not a pure sine wave in form.

In a normal r.f. oscillator circuit, the grid resistor value must be such that high r.f. output is obtained, if this is desired, without self-modulation or blocking.

The N.R.I. values show that loading of the tank circuit reduces both the r.f. tank voltage and the C bias voltage. Loading of a tank circuit reduces its Q factor, with the result that for a given amount of feed-back energy less r.f. voltage is developed. Since the r.f. voltage produces the C bias, this C bias lowers also.

Although loading increases the operating angle of the plate current, the peak plate current value is reduced due to the lowered r.f. voltage, and consequently the d.c. plate current is less. As previously explained, a lowered d.c. plate current results in a higher d.c. plate voltage just as was found by actual measurement in this experiment.

Instructions for Report Statement No. 46. In a practical oscillator circuit, it is entirely possible to encounter the condition in which the grid resistor opens up, giving infinity as the grid resistance value. The grid condenser is still in the circuit, but ordinarily the resistance of a small paper condenser like this is somewhere between 5,000 and 25,000 megohms, and for practical purposes this may be considered infinite. For this report statement, you will duplicate this open grid resistor condition and note its effect.

Remove the 10-megohm grid resistor from the *green* and *unmarked* s.g. coil terminals. Be sure that the 40,000-ohm resistor has been removed from trimmer condenser terminals *18* and *19*. Insert the phone tips in place of the U-shaped jumper wire in the phone jacks, connect the tester for r.f. tank voltage measurements, set the selector switch at the *V* range, then turn on the power pack and the N.R.I. Tester and listen to the phone for several minutes. Turn off your apparatus, then answer Report Statement No. *46*.

EXPERIMENT 47

Purpose: **To show that an r.f. amplifier stage having a coil in the plate circuit will provide r.f. gain; to show that the gain of an r.f. amplifier stage can be increased by tuning the secondary winding of the r.f. transformer in the plate circuit; to show that weak output coupling reduces the r.f. output voltage and the gain.**

Preliminary Discussion: First of all, we require for this experiment an unmodulated variable r.f. voltage source, so that we can feed a definite r.f. voltage value into the grid of the r.f. amplifier stage which is built as a part of this experiment.

The tuned grid r.f. oscillator which you constructed and used in the previous experiment gives a suitable variable-frequency r.f. voltage source; to vary its r.f. output voltage, we simply connect the 1,000-ohm potentiometer across the third winding (*gray* and *yellow* terminals) of the signal generator coil. Since the movable (center) terminal of the potentiometer is grounded to the chassis through the lead to terminal *9*, we can obtain the r.f. voltage between the chassis and either of the outer potentiometer terminals.

The complete schematic circuit diagram for the r.f. oscillator and r.f. amplifier used in this experiment is given in Figs. *21A* and *21B*. The second triode section of the type 6F8G tube serves as the r.f. amplifier stage.

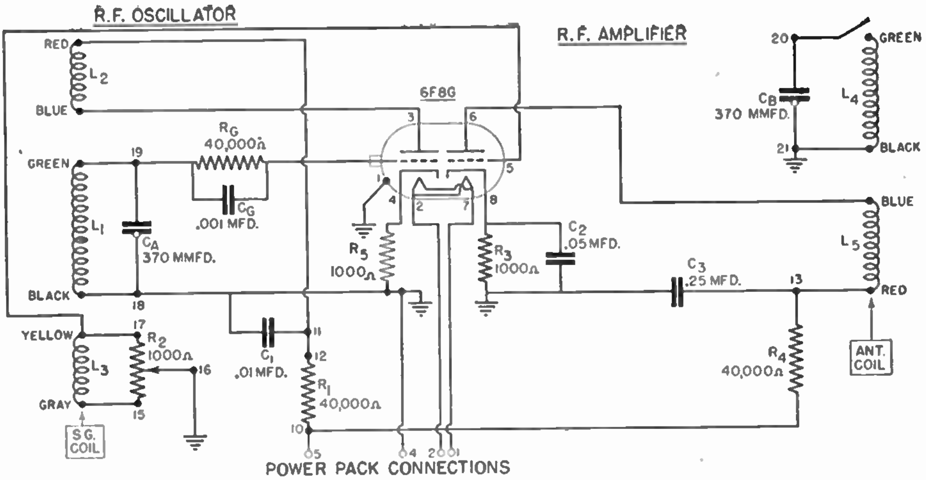


FIG. 21A. Schematic circuit diagram for the r.f. oscillator and r.f. amplifier which you build in Experiment 47. The connection from trimmer condenser terminal *20* to the *green* terminal of the antenna coil is not made until after you complete the first measurement for this experiment. If you desire, you can redraw this diagram in the spread-out form of Fig. *9B*, to secure valuable practice in reading and drawing schematic diagrams. Start out by drawing the two separate triode sections, placing them about four inches apart and making them about three times the size of the symbols shown here. Coils can be rearranged, but coil terminal markings must be kept the same. One method of redrawing this circuit is shown in Fig. *21B*; use this as a guide only if you encounter difficulties.

A 1,000-ohm resistor (R_3) in the cathode lead provides automatic C bias, and a .05-mfd. condenser (C_2) across this resistor by-passes r.f. signals so as to reduce degeneration. The antenna coil furnished you in Radio Kit *5RK* serves as the load for this r.f. amplifier stage, with the smaller of its two coils (L_5) being connected into the plate circuit. For one series of measurements, you use this coil alone as an untuned load. In another series of measurements, you will tune the secondary winding (L_4) of this r.f. output transformer with the 370-mmfd. trimmer condenser so as to secure a tuned load.

Step 1. To assemble the r.f. amplifier stage required for this experiment, first place before you the following parts:

.25-mfd. paper condenser (Part *3-2A*).
Three 40,000-ohm resistors (Parts *3-6B, C* and *D*).
1,000-ohm resistor (Part *3-5A*).
Standard broadcast band antenna coil (Part *5-6*).
370-mmfd. trimmer condenser (Part *5-9B*).
.05-mfd. paper condenser (Part *5-12*).

Connect a 40,000-ohm resistor between the *green* and *unmarked* terminals of the s.g. coil, to serve as the grid resistor for your r.f. oscillator. This will now be in parallel with the .001-mfd. condenser also connected to these terminals. Connect potentiometer terminal *17* to the *yellow* terminal of the s.g. coil, bringing the wire through chassis hole *i*. Connect potentiometer terminal *15* to the *gray* terminal of the s.g. coil, bringing the wire through chassis hole *j*. This places the potentiometer across the third winding of your s.g. coil, thereby providing variable r.f. output for your r.f. oscillator.

Mount the antenna coil in holes *jj* and *pp*, in a position such that the four terminal lugs of this coil will be above chassis holes *a*, *b*, *c* and *d*.

Mount the 370-mmfd. trimmer condenser in chassis hole *nn* in such a way that the tab of this condenser will be in hole *oo* and the adjusting screw will be adjustable from the top of the chassis through hole *x*. Identify this condenser as C_B on both sides of the chassis with metal-marking crayon and identify the terminals under the chassis by marking the number *20* alongside the condenser terminal nearest the edge of the chassis, and marking *21* alongside the other terminal. (These numbers can have the same positions as are indicated for trimmer condenser C_B in Fig. *25*.) You will now have two r.f. coils mounted above the chassis and two 370-mmfd. trimmer condensers mounted underneath the chassis.

Connect potentiometer terminal *17* to socket terminal *5* with hook-up wire.

Connect the .05-mfd. paper condenser between socket terminals *1* and *8*, then place a 1,000-ohm resistor in parallel with this condenser by connecting the resistor leads also to socket terminals *1* and *8*.

Connect socket terminal *6* to the *blue* terminal of the antenna coil, bringing the hook-up wire through chassis hole *d*.

Connect terminal *13* under the chassis to the *red* terminal of the antenna coil, bringing the hook-up wire through chassis hole *c*.

Connect a .25-mfd. condenser between terminals *13* and *14* under the chassis.

Connect a 40,000-ohm resistor between terminals *13* and *10* under the chassis. Bend the leads of all parts so that the parts are within the limits of the chassis. Make sure that leads do not accidentally touch adjacent bare leads or terminals.

Connect the *green* terminal of the antenna coil to terminal *20* of trimmer condenser C_B, bringing the hook-up wire through chassis hole *a*.

Connect the *black* terminal of the antenna coil to terminal *21* of C_B, bringing the hook-up wire through chassis hole *b*.

Ground terminal *21* of C_B to the chassis by connecting it to terminal *9* with hook-up wire.

START Unsolder temporarily the lead which is on the *green* terminal of the antenna coil, since your first measurements will be made with an untuned secondary winding on this coil. Connections underneath the chassis should now be as shown in Fig. *22*.

Step 2. To measure the r.f. output voltage before and after the secondary of the plate coil for the r.f. amplifier stage is tuned, first set your r.f. oscillator to a low radio frequency (about 600 kc.) by rotating trimmer condenser C_A as far as it will go in a clockwise direction, then turning it back one-fourth turn in a counterclockwise direction. (This trimmer condenser can be adjusted with a screwdriver inserted through chassis hole *u*.)

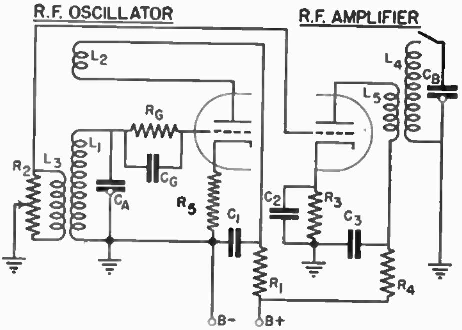


FIG. 21B. Spread-out version of the schematic diagram given in Fig. *21A*. Any circuit employing double-function tubes can be redrawn with the tube sections separated in this manner, if desired.

Prepare the N.R.I. Tester for r.f. voltage measurements by checking its calibration according to previous instructions, then place the black clip on the chassis, and place the red clip on the *yellow* terminal of the s.g. coil. Keep the test leads well apart from each other, and keep your hands and other parts of your body well away from these leads during measurement. to avoid effects of body capacity.

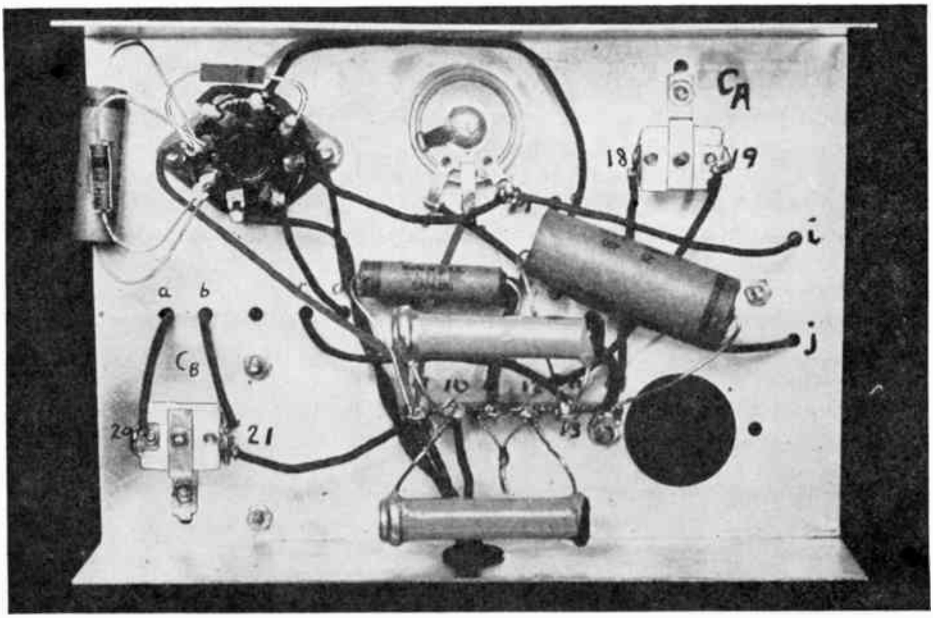


FIG. 22. The bottom of your r.f. chassis should appear like this after you have completed the assembly instructions given in Step 1 of Experiment 47.

Set the N.R.I. Tester to its *V* range, turn on the power pack and the N.R.I. Tester, wait half a minute, then rotate the potentiometer on the r.f. chassis with a screwdriver while watching the meter, to note how much control this potentiometer has upon the r.f. output voltage of your r.f. oscillator. Now set the potentiometer for an r.f. output of 2 volts by adjusting it until the meter reads 2 on the *AC* scale.

Without turning off the power pack or the N.R.I. Tester, move the red clip to the *green* terminal of the antenna coil (the coil marked *ANT*). Since there is only a 2-volt potential on the clip in both cases here, it is safe to touch it without turning off the power in this particular case. Read the meter on the *AC* scale, and record your result in Table *47* as the r.f. output voltage for an untuned load when using a *low* radio frequency.

Turn off the power pack, then reconnect to the *green* terminal of the antenna coil the lead which comes up through chassis hole *a*. Move the red clip to this *green* terminal, set the selector switch to *3 × V*, and adjust trimmer condenser C_B for maximum meter deflection. If this adjustment gives a voltage higher than 13.5 volts, switch to the *30 × V* range and continue adjusting C_B for a maximum meter deflection. Record your result in Table *47* as the r.f. output voltage in volts with a tuned load when using a *LOW* radio frequency.

If your r.f. output voltage value with tuned load is considerably less than the N.R.I. value, there is a possibility that the grid circuit wiring of the r.f. oscillator is picking up the signal of a strong local broadcast station at the oscillator frequency, thereby giving modulation. The remedy involves adjusting C_A about 1/4 turn in either direction, then retuning C_B for a maximum meter deflection, so as to make the oscillator frequency different from that of the broadcast station.

Turn off the power pack, then move the red clip to the *yellow* terminal of the s.g. coil. Turn on all apparatus, increase the frequency (to about 800 kc.) by rotating trimmer condenser C_A one turn more in the counter-clockwise direction (so that it is now 1¼ turns counter-clockwise from its maximum-capacity position), set the selector switch of the N.R.I. Tester to the *V* range, then adjust the potentiometer until a 2-volt reading is obtained on the *AC* scale. (Trimmer condenser C_A is chiefly a control over frequency, and has only a small effect upon the r.f. output voltage.)

Now unsolder temporarily the lead going to the *green* terminal of the antenna coil. Move the red clip to the *green* terminal of the antenna coil, measure the r.f. voltage between this terminal and the chassis while using the *V* range, and record your result in Table *47* as the r.f. output voltage in volts with an untuned load when using a *high* radio frequency.

Reconnect the lead to the *green* terminal of the antenna coil, tune trimmer condenser C_B for maximum output voltage while using the *30* × *V* range, read the meter, and record your result as the r.f. voltage in volts with a tuned load when using a *high* radio frequency.

Discussion: When an r.f. voltage of 2 volts was fed into the input of the r.f. amplifier stage while the load was untuned and the low radio frequency (about 600 kc.) was used, only .5 volt r.f. was obtained across the secondary terminals. The reason we get less voltage out of this r.f. amplifier stage than we put into it is that the coupling between the primary and secondary coils of the output transformer (the antenna coil) is very weak. It would be necessary to increase the coupling considerably in order to obtain amplification from this stage without tuning.

When the frequency of the r.f. oscillator was increased, a slightly higher N.R.I. output voltage value was obtained for the untuned load condition when the input was 2 volts r.f., but still the output voltage was less than the input voltage.

According to mathematical analysis, the voltage induced in the secondary of the output transformer depends upon three factors: *frequency*, the *mutual inductance* between the two coils of the output transformer, and the value of the *a.c. plate current*. (The voltage is actually equal to these three factors and the number 6.28 multiplied together.) The mutual inductance is fixed in this experiment since we do not vary the coupling between the coils. The a.c. plate current is likewise fixed since we fixed the a.c. grid voltage at 2 volts. The mathematical analysis thus tells us that the voltage induced in the secondary should go up when the frequency is increased. The experimental results confirmed this, because the N.R.I. value of r.f. output voltage increased from .5 volt to 1.2 volts when the frequency was raised.

Q Factor. When you place a 370-mmfd. trimmer condenser across the secondary of the output transformer, you have a series resonant circuit, for the voltage induced in the secondary acts *in series* with the inductance of the secondary coil and the capacity of the trimmer condenser. In regular N.R.I. lesson texts, you learned that the voltage across the coil (or the condenser) at resonance in a series resonant circuit is equal to Q times the a.c. supply voltage for the circuit, with Q being the reactance of the coil divided by the circuit resistance.

In this experiment, the source voltage value for your series resonant circuit is the voltage which you measured across the secondary terminals for the untuned condition. The Q factor of your secondary circuit is therefore equal to the r.f. output voltage you measured with tuned load divided by the r.f. output voltage measured with untuned load. For the low-frequency case, the N.R.I. Q factor value will be 15 ÷ .5, which is 30. For the high-frequency case, the N.R.I. Q factor value will be 63 ÷ 1.2, or about 52. We thus see that the Q factor of the series resonant circuit is considerably higher at the higher frequency.

Now let us consider why Q factor should increase with frequency. First of all, increasing the frequency raises the reactance of the coil in our resonant circuit, and this naturally raises the Q factor of the circuit because this Q is basically equal to coil reactance divided by circuit resistance. At the same time, however, the coil and circuit losses increase when frequency is increased, preventing us from securing as high a Q factor as might otherwise be possible. In practical resonant circuits, we often encounter the condition where the increased losses more than offset the increase in coil reactance, with the result that circuit Q factor and gain actually drop when frequency is increased.

N.R.I. lesson texts also pointed out that loading a resonant circuit with resistance reduces the Q factor of the resonant circuit, thereby reducing the over-all gain of the stage. When high-gain r.f. amplifier stages are desired, loading of resonant circuit is definitely to be avoided. This loading need not necessarily be in the form of a shunt resistor; serious loading can result from improper inductive coupling between the secondary and another circuit, from moisture in the coil, from leakage resistance in circuit parts, from improper placement of the coil in a metal shield, or from coupling the coil to the grid-cathode of a tube which draws grid current (such as a grid leak-condenser detector or a diode detector.)

Instructions for Report Statement No. 47. The effect which loading has upon the Q factor of a resonant circuit and the over-all gain of the r.f. amplifier stage which includes the resonant circuit can very readily be demonstrated. The over-all gain of the r.f. amplifier stage is simply the measured value of r.f. output voltage divided by the r.f. input voltage. (We fixed the r.f. input voltage at 2 volts in every case.) Thus, when using the higher radio frequency and a tuned load, the N.R.I. value of over-all gain for the r.f. amplifier stage becomes 63 ÷ 2, or 31.5; this indicates that our 2-volt input r.f. signal is amplified 31.5 times.

For this report statement, you are asked to give the over-all gain of your own r.f. amplifier stage before and after the tuned output circuit is loaded with a 40,000-ohm resistor. You can secure these values in the following manner.

FREQUENCY	R.F. OUTPUT VOLTAGE IN VOLTS WITH UNTUNED LOAD		R.F. OUTPUT VOLTAGE IN VOLTS WITH TUNED LOAD	
	YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.
LOW	.9	.5	15.	15
HIGH	1.5	1.2	54	63

TABLE 47. Record your results here for Experiment 47.

First obtain your value of over-all gain for the higher frequency and tuned load, by dividing the last value which you recorded in Table *47* (that for the r.f. voltage in volts with tuned load and high frequency) by the number 2 and record your result in Report Statement No. 47. Next, with your circuit connected exactly as it was for the last measurement in this experiment, place a 40,000-ohm resistor across your series resonant circuit by connecting it between terminals *20* and *21* of trimmer condenser C_B.

With this resistor connected, check the r.f. input voltage again (red clip on *yellow* terminal of s.g. coil, black clip on chassis, and selector switch at V) to make sure it is still 2 volts r.f., then measure the r.f. output voltage across the coil in the resonant circuit by moving the red clip to the *green* terminal of the antenna coil, setting the selector switch to $3 \times V$, and retuning trimmer condenser C_B for a maximum meter deflection. (If this gives a voltage higher than 13.5 volts, switch to the $30 \times V$ range and readjust C_B for a maximum reading.)

Divide your measured value of r.f. output voltage by 2, and record your result in Report Statement No. 47 as the over-all gain of your r.f. amplifier stage when the tuned output circuit is loaded with a 40,000-ohm resistor.

EXPERIMENT 48

***Purpose:* To show that the gain of an r.f. amplifier increases when the plate load impedance is increased.**

Preliminary Discussion: The r.f. amplifier stage used in the previous experiment employed transformer coupling to transfer energy from the plate circuit to the output circuit. Another widely used type of r.f. amplifier is that using either an r.f. choke coil or a parallel resonant circuit as the plate load, with a d.c. blocking condenser being used to couple the plate circuit to the input of the next stage. In this case, the input of the next stage must be shunted by a high resistance, so that the C bias voltage is applied to the stage without appreciably affecting the plate load impedance of the preceding stage.

The higher the impedance of the plate load being used in an r.f. amplifier stage, the higher will be the over-all gain of the stage. When a choke coil alone is being used as the plate load, its impedance will be a definite value which depends upon the inductance of the coil and the frequency of the signal. Any stray circuit capacity which acts in parallel with this plate load serves to reduce the plate load impedance and thus reduce the over-all stage gain. To secure maximum gain and at the same time counteract stray circuit capacities, the plate load inductance is often tuned to resonance by a shunt condenser so as to secure a parallel resonant circuit which has a high resistance at resonance. Stray circuit capacities then become a part of the tuning capacity, so that their presence is no longer objectionable.

There are two windings on the antenna coil form supplied you in Radio Kit 5RK-1, with one having more turns than the other. Since the winding having a higher number of turns will have the highest inductance and reactance, we can use each winding in turn as the plate load of our r.f. amplifier stage, and thus secure measurements of over-all gain for two different plate load inductance values. By feeding exactly 2 volts r.f. into the input of the r.f. amplifier and measuring the r.f. voltage developed across the load inductance, we can determine the over-all gain, just as was done in the previous experiment. The r.f. output voltage across the coil divided by the r.f. input voltage value of 2 will give the over-all stage gain.

After measuring the over-all gain when using low-reactance and high-reactance plate loads, we will tune the high-reactance load to resonance with a trimmer condenser and again determine the over-all gain. Since the resistance of the parallel resonant circuit at resonance is very much higher than the reactance of the coil alone, we should get the highest over-all gain with the tuned load.

Step 1. To measure the over-all gain of your r.f. amplifier stage while using a low-reactance coil as plate load, first unsolder the lead from the *green* terminal of the antenna coil, so

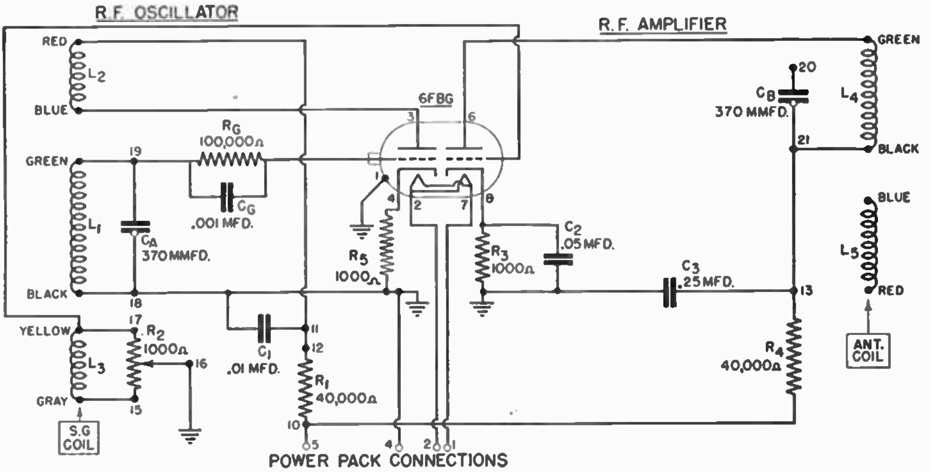


FIG. 23. This is the circuit which you use in Step 2 of Experiment 48. Resistor R_g should be 40,000 ohms instead of 100,000 ohms as shown.

that only the low-reactance primary winding will be effective in the plate circuit. Leave the rest of the circuit exactly as it was for the report statement measurement in the previous experiment. Trimmer condenser C_A should still be 1¼ turns off from its maximum clockwise setting.

Adjust the r.f. input voltage of your r.f. amplifier stage to 2 volts exactly as you did in the previous experiment (red clip on *yellow* s.g. coil terminal, black clip on chassis, selector switch at *V* and adjust the potentiometer to a meter reading of 2 volts on the *AC* scale).

Measure the r.f. voltage across the plate load by moving the red clip to the *blue* terminal of the antenna coil and leaving the selector switch set at *V*. Record your result in Table *48* as the r.f. voltage in volts across the plate load when the load is a low-reactance coil.

Divide your measured value of r.f. output voltage by the input voltage value of 2 to secure the over-all gain under this condition, and record your result in Table *48* as the over-all gain when the plate load is a low-reactance coil.

Step 2. To measure the over-all gain when using a high-reactance coil as the plate load, first make the following changes so as to secure the circuit arrangement shown in Fig. *23*.

Unsolder the lead from the *blue* terminal of the antenna coil, and push this lead entirely down through chassis hole *d*.

Unsolder the lead from the *red* terminal of the antenna coil, and push this lead entirely down through chassis hole *c*.

Unsolder the 40,000-ohm resistor from the terminals of trimmer condenser C_B.

Remove completely the lead which connects terminal *9* to trimmer condenser terminal *21*.

Unsolder the lead which is on trimmer condenser terminal *20*, and connect this lead to the free end of the lead which is on socket terminal *6*.

Connect to trimmer condenser terminal *21* the free end of the lead which is on terminal *13*.

Connect to the *green* terminal of the antenna coil the lead which comes out of hole *a*.

Adjust the r.f. input voltage of your r.f. amplifier stage to 2 volts (red clip on *yellow* terminal of s.g. coil, black clip on chassis).

Move the red clip to the *green* terminal of the antenna coil, set the selector switch to the *3* × *V* position, turn on your apparatus, and measure the r.f. plate load voltage for this connection. Record your result in Table *48* as the r.f. voltage in volts across the plate load when this load is a high-reactance coil.

Divide your measured r.f. output voltage value by the input voltage value of 2, and record your result also in Table *48* as the over-all gain for this same condition.

Step 3. To measure the over-all gain of your r.f. amplifier stage when using a tuned high-reactance coil as a plate load, first locate the common junction of the leads coming from chassis hole *a* and socket terminal *6*, and connect this junction to trimmer condenser terminal *20*. This connects C_B across L_4 in Fig. *23*.

STEP	NATURE OF PLATE LOAD	R.F. VOLTAGE IN VOLTS ACROSS PLATE LOAD		OVER-ALL GAIN	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
1	LOW-REACTANCE COIL	1.5	2.0	.75	1
2	HIGH-REACTANCE COIL	7.	10.8	3.5	5.4
3	TUNED HIGH REACTANCE COIL	45 30	57	22.5 15	28.5

TABLE 48. Record your results here for Experiment 48.

With the red clip still on the *green* terminal of the antenna coil and the black clip on the chassis, set the selector switch to *30* × *V* and adjust trimmer condenser C_B for a maximum meter reading so as to secure resonance. Measure the voltage under this condition, and record your result in Table *48* as the r.f. voltage in volts across the plate load when this load is a tuned high-reactance coil.

Divide your measured r.f. output voltage value by the input value of 2, and record your result in Table *48* as the over-all gain for this condition.

Discussion: The N.R.I. value for this experiment shows that as the plate load reactance or impedance is increased, the r.f. voltage goes up, and the over-all gain of the r.f. amplifier stage likewise increases. Note that an over-all gain value of 28.5 was obtained for Step 3 in the N.R.I. laboratory; this is higher than the rated amplification factor of 20 for each section of this 6F8G tube, so some explanation is required. Of course, we can always blame a disagreement like this upon normal inaccuracies in our measurements, but a more likely explanation is the fact that a certain amount of regeneration exists in this r.f. amplifier stage due to the unneutralized inter-electrode capacity between the plate and grid of the triode section. This regeneration raises the over-all gain of the stage.

Instructions for Report Statement No. 48. A by-pass condenser is commonly placed across a cathode resistor to prevent degeneration due to an a.c. voltage drop across this resistor. We should therefore be able to introduce degeneration into our r.f. amplifier circuit by removing the .05-mfd. by-pass condenser which is shunting the 1,000-ohm cathode resistor.

The purpose of this report statement is to prove that removal of the by-pass condenser actually causes degeneration and a reduction in over-all gain.

Unsolder from terminal *8* the lead of the .05-mfd. condenser, while leaving the rest of your circuit exactly as it was for the last measurement in Step 3. The test clips should still be in position to measure the r.f. voltage between the *green* antenna coil terminal and the chassis. Use the *30* × *V* range. When you obtain the r.f. output voltage value for this condition, divide it by 2 to get the over-all gain of the stage, and record your result in Report Statement No. 48. After this, answer the last half of this report statement, in which you compare this measured value of over-all gain with that which you recorded for Step 3.

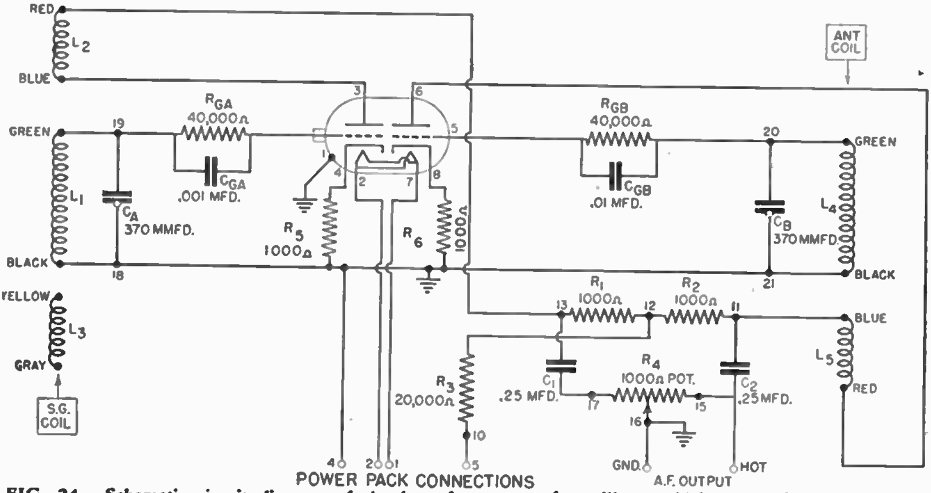


FIG. 24. Schematic circuit diagram of the beat frequency r.f. oscillator which you build as a part of Experiment 49.

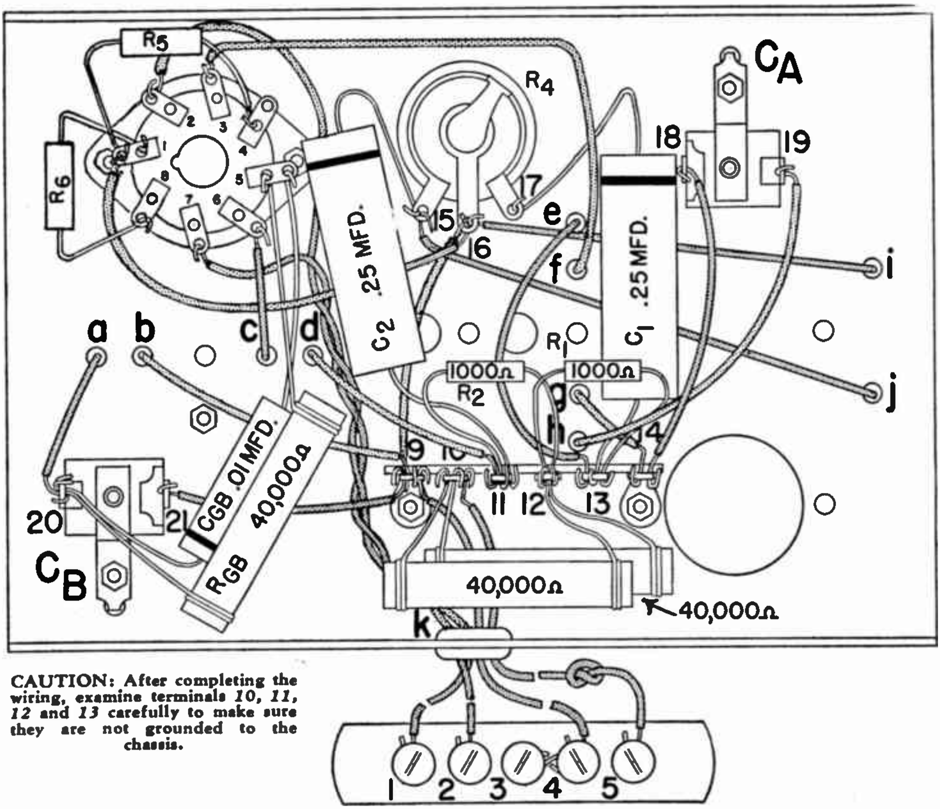
EXPERIMENT 49

Purpose: **To build a beat frequency oscillator and adjust it to zero beat; to show that changing the value of the grid leak resistance, changing the value of the grid condenser, changing the amount of loading on the tank circuit, or the presence of body capacity near the tank circuit of one of the r.f. oscillator circuits will change the beat frequency.**

Preliminary Discussion: In this experiment, you will build two r.f. oscillators, feed their outputs into a common mixing circuit, and use the N.R.I. Tester as a detector to rectify the resulting signal and give an audio tone which you can hear in the headphone. Each r.f. oscillator will have its own trimmer condenser, so that by adjusting one trimmer condenser you can make the two r.f. oscillators very nearly equal in frequency. Then, by means of the potentiometer which is connected to give a vernier control over frequency, you can adjust the system more accurately until both r.f. oscillators are very nearly the same in frequency. You then have the condition known as *zero beat.*

The schematic circuit diagram for this beat frequency oscillator is given in Fig. *24* for reference purposes, but you will use the semi-pictorial bottom and top views of the chassis in Figs. *25* and *26* respectively as your guides for assembling this oscillator.

Step 1. To assemble a beat frequency r.f. oscillator, first disconnect



CAUTION: After completing the wiring, examine terminals *10, 11, 12* and *13* carefully to make sure they are not grounded to the chassis.

FIG. 25. Bottom view of the r.f. chassis, showing how parts and wiring should appear after you have built your beat frequency r.f. oscillator according to the instructions given in Step 1 of Experiment 49.

the four leads from the power pack output terminals. Remove the type 6F8G tube from its socket, as a safety precaution during assembly.

Unsolder from the various terminals above and below the r.f. chassis all of the fixed condensers, resistors and wires except the power supply leads on terminals *2*, *7*, *9*, *10*, and the potentiometer ground lead.

When the chassis is placed upside down for this work, it is resting directly on the two coils. Excessive pressure on the chassis, or sliding the chassis around on a rough-surfaced workbench may damage the coils, so it is a good idea to place several thicknesses of cloth between the coils and the bench, or prop up the chassis on small boxes.

Remove surplus solder from the lugs on the tube sockets, the terminal strip and the other parts both above and below the chassis. Save all lengths of wire, and use these lengths as much as possible for the beat oscillator connections now to be described.

You should now have the signal generator coil and the antenna coil mounted above the chassis; below the chassis there should be the 6-lug terminal strip, trimmer condensers C_A and C_B, the 1,000-ohm potentiometer and the tube socket, with the four power supply wires still in position and going out of the chassis through the rubber grommet.

a. Connect two 1000-ohm resistors to socket terminals *1*, *4*, and *8* just as shown in Fig. *25*. (Use Figs. *25* and

26 as guides to determine the best time for soldering each joint.)

b. Connect socket terminal *1* to grounded center terminal *16* of the potentiometer.

c. Connect a 7-inch length of hookup wire to potentiometer terminal *16*, bringing the other end of this wire through chassis hole *i*, and leave this wire projecting above the chassis to serve as the grounded r.f. output lead of this beat frequency oscillator.

d. Connect terminal *9* to trimmer condenser terminal *21*.

e. Connect terminal *9* to the *black* terminal of the antenna coil, running the wire through chassis hole *b*.

f. Connect trimmer condenser terminal *20* to the *green* terminal of the antenna coil, running the wire through chassis hole *a*.

g. Connect socket terminal *6* to the *red* terminal of the antenna coil, running the wire through chassis hole *c*.

h. Connect terminal *11* to the *blue* terminal of the antenna coil, running the wire through chassis hole *d*. This completes the four connections to the antenna coil.

i. Connect socket terminal *3* to the *blue* terminal of the s.g. coil, running the wire through chassis hole *f*.

j. Connect a .01-mfd. paper condenser between socket terminal *5* and trimmer condenser terminal *20*.

k. Connect a 40,000-ohm resistor between socket terminal *5* and trimmer condenser terminal *20*, so that this resistor is in parallel with the .01-mfd. condenser.

l. Connect terminal *13* to the *red* terminal of the s.g. coil, running the wire through chassis hole *e*.

m. Connect terminal *14* to the *black* terminal of the s.g. coil, running the wire through chassis hole *g*.

n. Connect terminal *14* to trimmer condenser terminal *18*.

o. Connect trimmer condenser terminal *19* to the *green* terminal of the

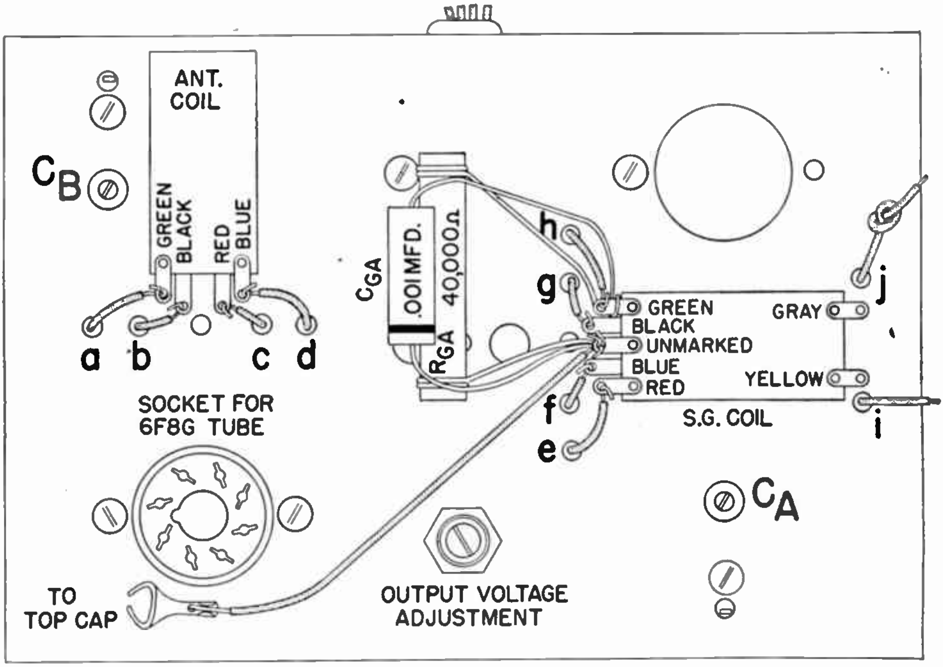


FIG. 26. Top view of the r.f. chassis, showing how parts and wiring should appear after construction of the beat frequency r.f. oscillator in Experiment 49.

s.g. coil, running the wire through chassis hole *h*.

p. Connect a .25-mfd. paper condenser between terminal *13* and potentiometer terminal *17*. Outside foil connections for paper condensers are unimportant in this beat oscillator and can be disregarded.

q. Connect a .25-mfd. paper condenser between terminal *11* and potentiometer terminal *15*.

r. Connect an 8-inch length of hookup wire to potentiometer terminal *15*. Bring the wire up through chassis hole *j*, and leave this wire projecting above the chassis to serve as the hot output lead of this beat frequency oscillator. Tie a simple knot about 1½ inches from the free end of this lead for identifying purposes.

s. Connect two 40,000-ohm resistors in parallel between terminals *10* and *12*. Adjust the positions of the resistors so that they are within the limits of the chassis but do not touch either the chassis or other terminals.

t. Connect a 1,000-ohm resistor between terminals *11* and *12*.

u. Connect a 1,000-ohm resistor between terminals *12* and *13*.

v. Connect the top cap lead to the *unmarked* lug on the s.g. coil, insert the type 6F8G tube in its socket, and place the grid clip on the top cap of this tube.

w. Connect a .001-mfd. condenser between the *green* terminal and the *unmarked* terminal of the s.g. coil.

x. Connect a 40,000-ohm resistor between the *green* and *unmarked* terminals of the s.g. coil, so that this resistor is in parallel with the .001-mfd. condenser.

This completes the wiring of your beat frequency oscillator. Before proceeding any further, check your work carefully against the semi-pictorial diagrams in Figs. *25* and *26* to be sure you have made every connection correctly. By now, you should be able to make this check against a diagram without detailed instructions.

Step 2. To adjust your beat frequency oscillator for zero beat, first provide power for your oscillator by connecting the two twisted power supply wires to power pack output terminals *1* and *2*, connecting to output terminal *5* the single wire which comes through the grommet and has a knot, and connecting the remaining single grommet wire to output terminal *4*.

Adjust the potentiometer on the r.f. chassis to its mid-position, so that the movable arm underneath the chassis is in line with the center terminal lug of the potentiometer.

Set each trimmer condenser in turn to maximum capacity by rotating in a clockwise direction with a screwdriver inserted through the adjusting hole on top of the chassis, then turn each adjusting screw back *one complete turn* in a counter-clockwise direction.

To listen to the audio beat note produced by your beat frequency oscillator, insert the headphone cord tips in the *PHONE* jacks of the tester, set the selector switch to the *V* range, insert the test probes in the V_{AC} jacks, place the black clip on the output lead which comes through chassis hole *i*, and place the red clip on the hot output lead which comes through chassis hole *j*.

Turn on the power pack, turn on the N.R.I. Tester, wait about half a minute for tubes to warm up, then adjust trimmer condenser C_A with a screwdriver while listening to the phone, until you hear a squeal. As you rotate the adjusting screw slowly through the position which gives the squeal, you will note two positions close together at which the high-frequency squeal is heard, with a mid-

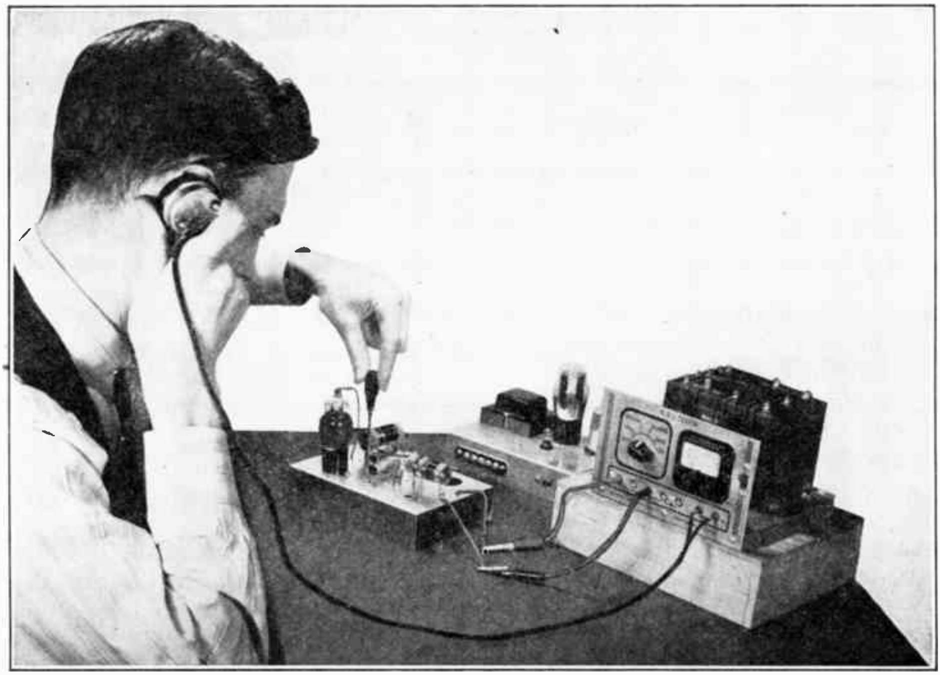


FIG. 27. If you arrange your beat frequency r.f. oscillator, power pack and N.R.I. Tester on your workbench in the manner shown here, there will be little chance for your hands and tester leads to affect the frequency of either of the r.f. oscillator circuits.

position between these points where the squeal is very low or there is no sound at all; this is the *zero beat* position. You may have some difficulty in adjusting exactly to zero beat, so set the trimmer condenser at the lowest possible pitch in between the squeals, then adjust the 1,000-ohm potentiometer on the r.f. chassis until you obtain zero beat. At this position of the potentiometer, no sound will be heard in the headphone, but a slight adjustment of the potentiometer in either direction will result in an audible sound. The potentiometer permits a more accurate adjustment to zero beat than is possible with the trimmer condenser.

Whenever adjusting your beat frequency oscillator for zero beat, keep your hand as far away from the type 6F8G tube as possible, and keep the test leads and the phone cord also away from this tube. If you arrange your apparatus in the manner shown in Fig. 27, you should have no difficulty in keeping these parts away from the highly critical 6F8G tube.

Step 3. To determine the effect of body capacity upon your beat frequency oscillator, first adjust the potentiometer so that zero beat will be obtained when your hand and the adjusting screwdriver are well away from the oscillator chassis. This may take considerable patience; you will have to find the potentiometer position which, even though it causes a squeal while your hand and the screwdriver are in position, gives zero beat when the screwdriver and hand are removed. If you wish, you can make an anti-capacity screwdriver from a piece of wood about 12 inches long and ¼ inch in diameter (such as wood dowel rod) by carving one end of the rod to the shape of your screwdriver blade and using this to adjust the potentiometer.

Having secured zero beat, bring one of your fingers slowly toward the signal generator coil while listening to the phone. Note that as you approach the coil, a point is reached at which a low-frequency audible note is heard, and this increases in pitch as you move closer to the coil. When you move entirely away from the coil, zero beat is entirely restored again.

Try this same experiment now on the 6F8G tube. Observe that you can change the pitch by changing the number of fingers which are in contact with the glass envelope of the tube.

Step 4. To determine how the beat frequency output of your oscillator is affected by loading of the tank circuit, turn off all apparatus and connect one lead of a 220-ohm resistor to the *gray* terminal of the s.g. coil by means of a temporary soldered hook joint. Adjust the other resistor lead so that it will make contact with the *yellow* s.g. coil terminal when the lead is pressed with a stick of wood (such as a ruler).

With the other resistor lead still unconnected, remove your hands from the chassis, turn on the power pack and the N.R.I. Tester, wait three or four minutes for all parts to assume normal operating conditions, then listen for zero beat again. Readjust the potentiometer if necessary in order to obtain zero beat.

Without turning off your apparatus, connect the 220-ohm resistor across winding L_3 of the s.g. coil by pressing the free lead of this resistor against the *yellow* s.g. coil terminal with a wooden rod, keeping your hand well away from the 6F8G tube; listen to the phone while doing this. You should now hear an audible tone having a fairly high pitch for the 220-ohm resistor acts as a load upon one r.f. oscillator, changing its frequency enough to create an audible beat note.

Step 5. To determine the effect of changing the grid leak resistance, place an 18,000-ohm resistor in parallel with 40,000-ohm grid resistor R_{GA} in the following manner:

First remove the 220-ohm resistor from the *gray* and *yellow* s.g. coil terminals.

Connect one lead of an 18,000-ohm resistor to the *green* terminal of the s.g. coil by means of a temporary soldered lap joint, being careful not to unsolder the other leads on the terminal.

Adjust the other lead of the 18,000-ohm resistor so that it does not touch anything, remove your hand, turn on the power pack and the N.R.I. Tester, wait about three or four minutes for operating conditions to be reached, then listen to the beat note and readjust the potentiometer for zero beat if necessary.

Without turning off any apparatus and while still listening to the phone, press the free lead of the 18,000-ohm resistor against the *unmarked* terminal of the s.g. coil with a wooden rod. A distinctly audible note having a fairly high pitch should now be heard, proving that lowering of the grid resistor value affects the frequency of one r.f. oscillator.

Step 6. To determine how the beat frequency output of your oscillator is affected by an increase in the capacity of the condenser across the grid leak, first turn off all apparatus and disconnect the 18,000-ohm resistor from the s.g. coil terminal. Connect one lead of a .05-mfd. condenser to the *green* s.g coil terminal by means of a temporary soldered lap joint, adjust the other lead so that it is near but not touching the *unmarked* s.g. coil terminal, then turn on your apparatus, wait about four minutes, then readjust the potentiometer if necessary to secure exactly zero beat again. Now press the free lead of the .05-mfd. condenser on the *unmarked* terminal with your wooden rod. You should be able to hear in the phone an audible beat note having a fairly high frequency. Placing this condenser in parallel with the .001-mfd. condenser gave a combined capacity of .051-mfd., since the capacity of condensers in parallel add. Turn off your apparatus and remove the .05-mfd. condenser.

Discussion: When two r.f. signals having slightly different frequencies are combined, the amplitude of the resulting signal varies in a manner corresponding to the difference between the frequencies of the two original r.f. signals. If this resulting signal is passed through a rectifier circuit such as that used in the N.R.I. Tester, a signal having this difference frequency will be obtained. If this rectified signal is fed into a sound-reproducing unit such as your headphone and if the difference frequency is in the audio spectrum, an audible tone will be heard. When both r.f. signals have exactly the same frequency, the difference frequency is zero and consequently there is no audible tone. As was already pointed out, this condition is known as *zero beat.*

Theoretically, it should be possible to obtain an extremely low-frequency audio signal by making the two r.f. signals only slightly different in frequency, but you probably observed that the audio signal disappears suddenly as you lower the beat frequency by bringing the r.f. oscillators closer together in frequency. When the r.f. signal from one oscillator enters the other oscillator, and the difference between the frequencies is quite small, an inter-action occurs which causes the oscillators to synchronize or lock in step with each other, so that both oscillate at the same frequency. In other words, as the difference frequency is lowered slowly, a low audio frequency is reached at which there is a sudden transition to zero beat.

This automatic synchronization between oscillators occurs due to the coupling existing between the parts and leads of the two r.f. oscillator circuits (the plate-to-plate inter-electrode capacity between the two triode sections of the tube, and the common coupling provided by the two .25-mfd. condensers and the 1,000-ohm potentiometer in the mixing circuit). At low frequency difference values, only a small amount of mutual coupling is required to cause this locking action.

In a practical beat frequency oscillator circuit, separate oscillator tubes are employed. Each r.f. circuit, including its tube, is placed in its own shielded compartment to reduce coupling to a minimum. Furthermore, the outputs of the individual oscillators are very weakly coupled to the common output circuit, so as to minimize inter-action through this channel.

Oscillator stability is a highly important radio problem, particularly in selective superheterodyne receivers. In these receivers, any drifting in the frequency of the oscillator destroys the accuracy of the receiver alignment, destroys the calibration of the receiver tuning dial, causes distortion, and even causes a reduction in signal strength in certain cases where highly selective i.f. amplifier stages are being used.

We normally associate a change in oscillator frequency with a change in either the inductance or capacity of the oscillator tank circuit. You demonstrated this fact in this experiment by adding your body capacity to the tank circuit capacity when you brought a finger near the signal generator coil. This changed the frequency of the r.f. oscillator using this coil, with the result that you heard a beat note.

The frequency of an r.f. oscillator can change even though the inductance or capacity values in the tank circuit are not altered directly. For example, any circuit change which affects the over-all gain of the oscillator stage will affect the input capacity of the oscillator stage and thereby change the resonant frequency, because this input capacity is in parallel with the tank circuit capacity. A more detailed analysis will show why this is true.

As was previously explained, the input capacity of a tube is the sum of four individual capacity values: *1. The grid-cathode inter-electrode capacity; 2. The grid-plate inter-electrode capacity; 3. A value equal to the grid-plate capacity multiplied by the true gain of the tube; 4. Stray grid circuit capacities,* such as that between the grid and cathode leads and terminals. Since the gain of the circuit affects the third of these individual capacities, it also affects the input capacity.

The input capacity of an oscillator tube can be considered as acting in parallel with the tank circuit capacity simply because the grid leak and grid condenser act essentially as a short-circuit path for r.f. current (reference to the schematic circuit diagram in Fig. *24* will help you to understand this). Any capacity in parallel with the tank capacity naturally increases the total tank circuit capacity, thereby lowering the resonant frequency.

Having shown how any change in the gain of an oscillator stage will affect the frequency of the oscillator, let us now consider how the application of a load to the tank circuit affects the gain. (Placing a 220-ohm load resistor between the *yellow* and *gray* terminals of the s.g. coil in Step 4 loads the tank circuit indirectly, giving exactly the same effect as if you placed a resistor across the tank circuit).

You will recall that when you placed a 40,000-ohm resistor across a tank circuit in a previous experiment, the measured value of C bias voltage changed. The C bias voltage therefore changed in Step 4 also, moving the operating point of the tube to a different region on the characteristic curve, and this changed the true amplification of the circuit (the true amplification varies with the slope of the characteristic curve).

Changing the value of the C bias resistor from 40,000 ohms in Step 5 affects the C bias voltage directly, for the rectified grid current flows through a lower resistance value and thus develops a lower voltage across the grid resistor for C bias purposes. As we just found out, a change in C bias changes the operating point and thus changes the true amplification of the circuit.

When you changed the grid condenser value from .001 mfd. to a value slightly larger than .05 mfd. in Step 6, you again changed the C bias voltage; the higher the capacity of this grid condenser, the closer to the peak value of the rectified grid current will be the voltage developed across the grid resistor.

Thus, every change which you made in this experiment affected the *C bias voltage*, the *amplification* of the oscillator circuit, the *input capacity*, the total effective *tank circuit capacity*, the *resonant frequency* of the tank circuit, the *output frequency* of the r.f. oscillator stage, and consequently *the frequency of the audio beat note.*

Temperature is another factor which can affect the frequency of an individual r.f. oscillator stage and thereby affect the frequency of the audio beat note produced by a beat frequency oscillator. Changes in temperature affect the physical dimensions of all parts in an oscillator circuit, with the changes in the tank circuit coil and condenser being the most important. In practical beat frequency oscillator circuits, identical parts are used in both r.f. oscillator circuits so that changes in temperature will affect each circuit identically, and even then the oscillators are allowed to operate for some time before an attempt is made to adjust for zero beat.

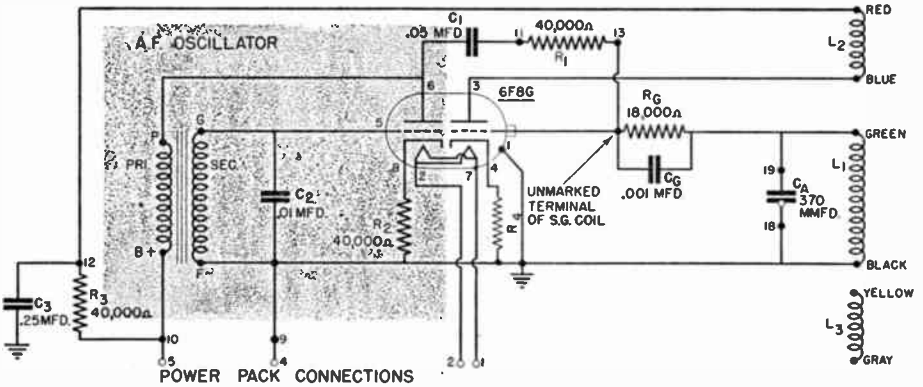


FIG. 28. Schematic circuit diagram for the grid-modulated r.f. oscillator which you build in Step 1 of Experiment 50.

Instructions for Report Statement No. 49. So far, we have only assumed that both r.f. oscillator circuits were operating and producing the audio beat note. For this report statement, you will prove this to be true by stopping one of the r.f. oscillators; if this stops the audio beat note, you will know that both r.f. oscillators must be working in order to produce the beat note.

With your beat frequency oscillator connected just as it was after completing Step 6, turn on your apparatus and adjust for an audible beat note (not for zero beat). It is highly important that a ground wire be connected to output terminal *3* of the power pack during this test. This ground wire should always be connected to this terminal. Now remove the clip from the top cap of the type 6F8G tube so as to stop the r.f. oscillator circuit which employs this top cap as its grid terminal, note the effect upon the beat note, and answer Report Statement No. 49. Be sure to turn off all apparatus when you have completed this test.

EXPERIMENT 50

Purpose: To build an r.f. oscillator which is grid-modulated by an a.f. oscillator; to build an r.f. oscillator which is cathode-modulated by an a.f. oscillator; to build an r.f. oscillator which is plate-modulated by an a.f. oscillator.

Step 1. To build an r.f. oscillator which is grid-modulated by an a.f. oscillator, as shown in the schematic circuit diagram in Fig. 28, carry out the following steps while using the semi-pictorial diagrams in Figs. *29* and *30* as your guides.

✓*a.* Remove the 6F8G tube from its socket, then remove from your oscillator chassis all leads except the four power leads on terminals *2*, *7*, *9*, *10*,

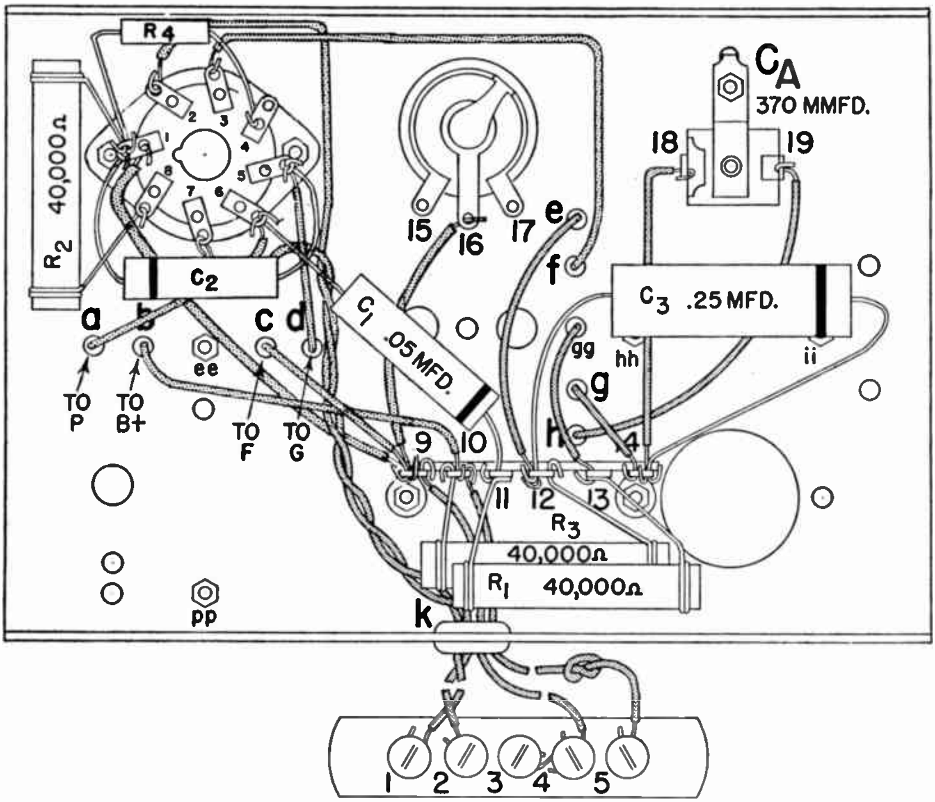


FIG. 29. Bottom view of the r.f. chassis, showing how it should appear after you have assembled the grid-modulated r.f. oscillator according to the instructions given in Step 1 of Experiment 50.

and on potentiometer terminal *16*. Remove all fixed resistors and paper condensers. Remove the antenna coil and its associated trimmer condenser C_B, but leave the remaining parts on the chassis. Remove surplus solder from the lugs of the parts still on the chassis.

b. Mount the audio transformer on top of the chassis in holes *ee* and *pp*, in such a position that the transformer lugs will be above chassis holes *a*, *b*, *c* and *d*.

c. Connect a 1000-ohm resistor to socket terminals *1* and *4*.

d. Connect a 40,000-ohm resistor between socket terminals *1* and *8*.

e. Connect socket terminal *1* to terminal *9*.

f. Connect a .01-mfd. condenser between socket terminals *1* and *5*.

g. Connect socket terminal *5* to terminal *G* of the audio transformer, running the wire through chassis hole *d*.

h. Connect a .05-mfd. condenser between socket terminal *6* and terminal *11*.

i. Connect socket terminal *6* to terminal *P* of the audio transformer, running the wire through chassis hole *a*.

j. Connect socket terminal *3* to the *blue* terminal of the s.g. coil, running the wire through chassis hole *f*.

k. Connect terminal *10* to the *B+* terminal of the audio transformer, running the wire through chassis hole *b*.

l. Connect terminal *9* to the *F* terminal of the audio transformer, running the wire through chassis hole *c*.

m. Connect terminal *14* to terminal *18* of trimmer condenser C_A.

n. Connect trimmer condenser terminal *19* to the *green* terminal of the s.g. coil, running the wire through chassis hole *h*.

o. Connect terminal 12 to the *red* terminal of the s.g. coil, running the wire through chassis hole *e*.

p. Connect terminal *13* to the *unmarked* terminal of the s.g. coil, running the wire through chassis hole *gg* (this is the unmarked hole located between marked holes *f* and *g*).

q. Connect terminal *14* to the *black* terminal of the s.g. coil, running the wire through chassis hole *g*.

r. Connect a .25-mfd. condenser between terminals *12* and *14*.

s. Connect a 40,000-ohm resistor between terminals *10* and *12*.

t. Connect a 40,000-ohm resistor between terminals *11* and *13*.

u. Connect the grid clip lead to the *unmarked* terminal of the s.g. coil.

v. Connect an 18,000-ohm resistor between the *green* and *unmarked* terminals of the s.g. coil.

w. Connect a .001-mfd. condenser between the *green* and *unmarked* terminals of the s.g. coil, in parallel with the 18,000-ohm resistor.

x. Connect your completed oscillator to the power pack by placing the two twisted leads on output terminals *1* and *2*, the knotted lead on terminal *5*, and the remaining lead on output terminal *4*.

y. Insert the type 6F8G tube in its socket, and place the grid clip on the top cap of this tube.

Testing Instructions. To listen to the audio signal at the output of your modulated r.f. oscillator, first prepare your N.R.I. Tester for audio listening tests as previously instructed (probes in V_{AC} jacks, selector switch at *V* and

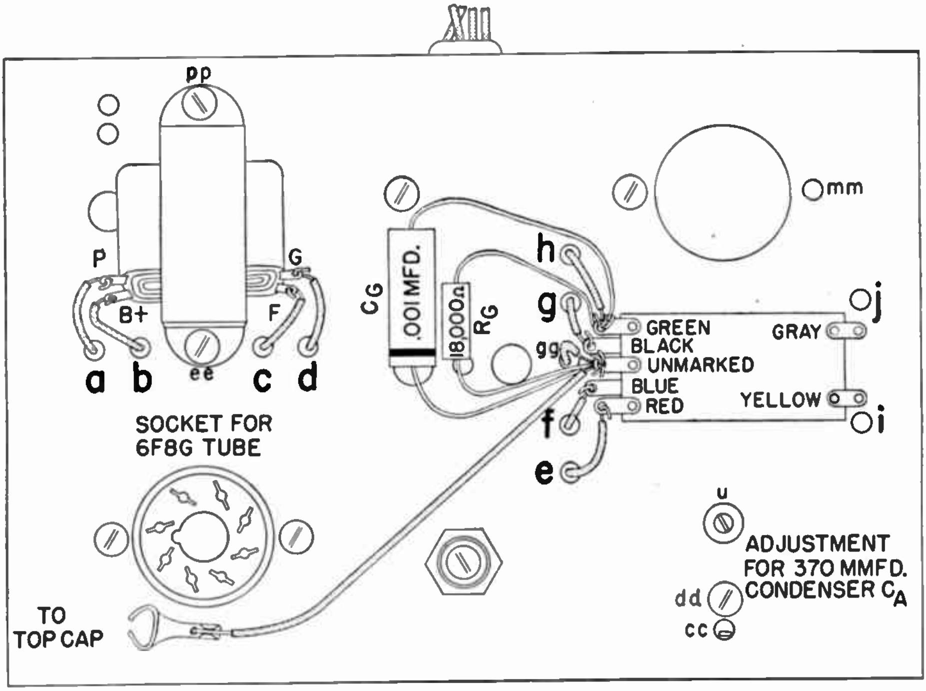


FIG. 30. Top view of the completed grid-modulated r.f. oscillator.

phone tips in *PHONE* jacks). Place one test clip on the *gray* terminal of the s.g. coil, and place the other test clip on the *yellow* terminal; polarity of connections does not matter.

Turn on the power pack, turn on the N.R.I. Tester, and listen to the phone after the tubes have warmed up. You should hear a clear audio tone if you have followed these instructions correctly. Turn off all apparatus now.

Step 2. To build an r.f. oscillator which is cathode-modulated by an a.f. oscillator, make the following changes in your grid-modulated oscillator so as to secure the cathode-modulated oscillator circuit shown in schematic form in Fig. *31*.

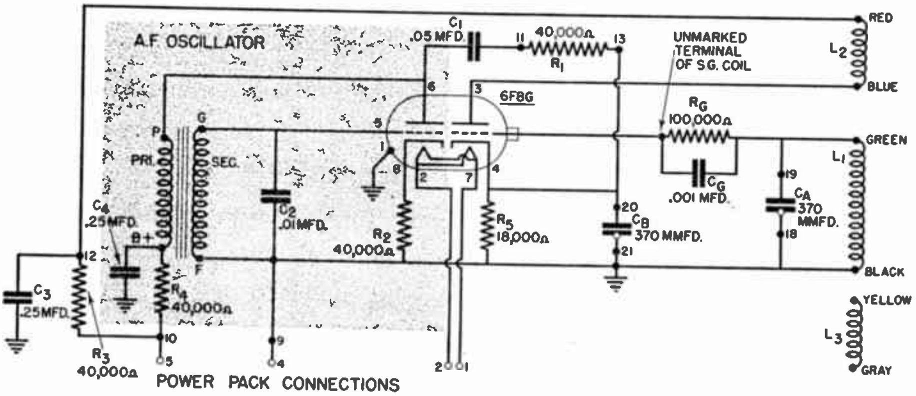


FIG. 31. Schematic circuit diagram of the cathode-modulated r.f. oscillator which you build for Step 2 of Experiment 50.

a. Mount your remaining 370-mmfd. trimmer condenser underneath the chassis in mounting hole *nn*, then adjust this condenser (identified as C_B) for maximum capacity by rotating the adjusting screw as far as it will go in a clockwise direction with a screwdriver inserted through chassis hole *x*.

b. Remove the 1000-ohm resistor from terminals *1* and *4* of the 6F8G tube socket. Make sure, however, that the ground lead (from terminal *9*), cathode resistor R_2, and by-pass condenser C_2 remain on terminal *1* as this is the ground return point for the audio oscillator as well as for the r.f. oscillator.

c. Remove the 18,000-ohm resistor from the *green* and *unmarked* terminals of the s.g. coil, and connect in its place a 100,000-ohm resistor. Leave the .001-mfd. condenser connected to the *green* and *unmarked* terminals so that it is now in parallel with the 100,000-ohm resistor.

d. Disconnect from the *unmarked* terminal of the s.g. coil the lead which comes up through chassis hole *gg*, push this lead back down through the chassis hole, add a 2-inch length of hook-up wire to it by means of a temporary soldered joint, and connect this extended lead to socket terminal *4*.

e. Connect the 18,000-ohm resistor between socket terminal *4* and terminal *9*.

f. Connect terminal *9* to terminal *21* of trimmer condenser C_B.

g. Connect socket terminal *4* to terminal *20* of trimmer condenser C_B.

h. Remove from terminal *10* the lead which goes through chassis hole *b*, connect one lead of a 40,000-ohm resistor to terminal *10*, and connect the other lead of this resistor to the wire which you just disconnected from terminal *10*.

i. Connect a .25-mfd. condenser between trimmer condenser terminal *21* and the last joint made in the previous step (this is equivalent to connecting the condenser between terminal *21* and the *B+* terminal of the audio transformer).

j. Arrange all parts now so that the leads do not touch each other when the parts are within the limits of the chassis, so as to permit turning the chassis over.

Testing Instructions. Adjust trimmer condenser C_A to one turn less than maximum capacity by rotating the adjusting screw as far as it will go in a clockwise direction, then turning back counter-clockwise one full turn. Listen to the output signal with the N.R.I. Tester by placing the test clips on the *gray* and *yellow* terminals of the s.g. coil. Turn off all apparatus.

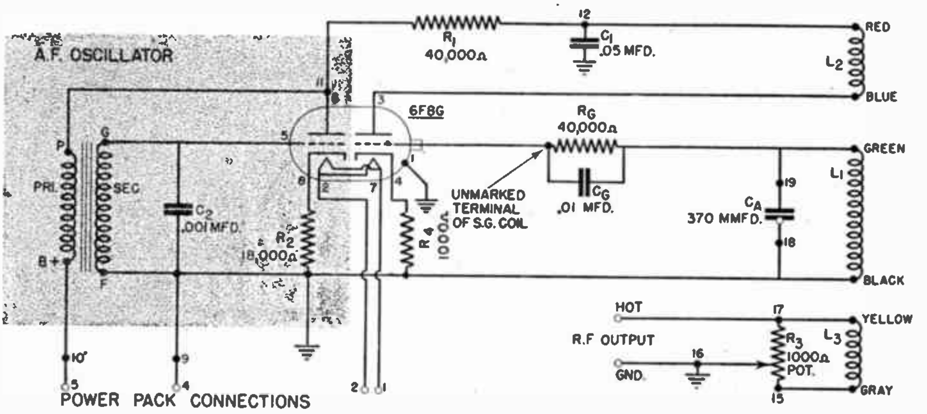


FIG. 32. Schematic circuit diagram of the plate-modulated r.f. oscillator which you build for Step 3 of Experiment 50. You are to leave this oscillator set up for use in connection with experiments in the next manual.

START *Step 3. To build an r.f. oscillator which is plate-modulated by an a.f. oscillator,* according to the schematic circuit diagram in Fig. *32*, carry out the following steps while using the semi-pictorial diagram in Fig. *33* and the top view in Fig. *34* as your guides.

a. Disconnect the experiment from the power pack, remove the tube, then unsolder all wires and leads above and below the chassis except the power supply leads on terminals *2, 7, 9, 10,* and potentiometer terminal *16*.

b. Remove trimmer condenser C_B. The only parts which you should now have left on the chassis are the audio transformer and signal generator coil above the chassis, and the tube socket, 1,000-ohm potentiometer, 370-mmfd. trimmer condenser C_A, the six-lug terminal strip, and the four power pack leads under the chassis.

c. Connect terminal *9* to the *F* terminal of the audio transformer, running the wire through chassis hole *c*.

d. Connect terminal *9* to socket terminal *1*.

e. Connect a 1000-ohm resistor between socket terminals *4* and *1*.

f. Connect an 18,000-ohm resistor between socket terminals *1* and *8*.

g. Connect terminal *5* to the *G* terminal of the audio transformer, running the wire through chassis hole *d*.

h. Connect a .001-mfd. condenser between socket terminals *1* and *5*.

i. Connect terminal *6* to the *P* terminal of the audio transformer, running the wire through chassis hole *a*.

j. Connect terminal *10* to the *B+*

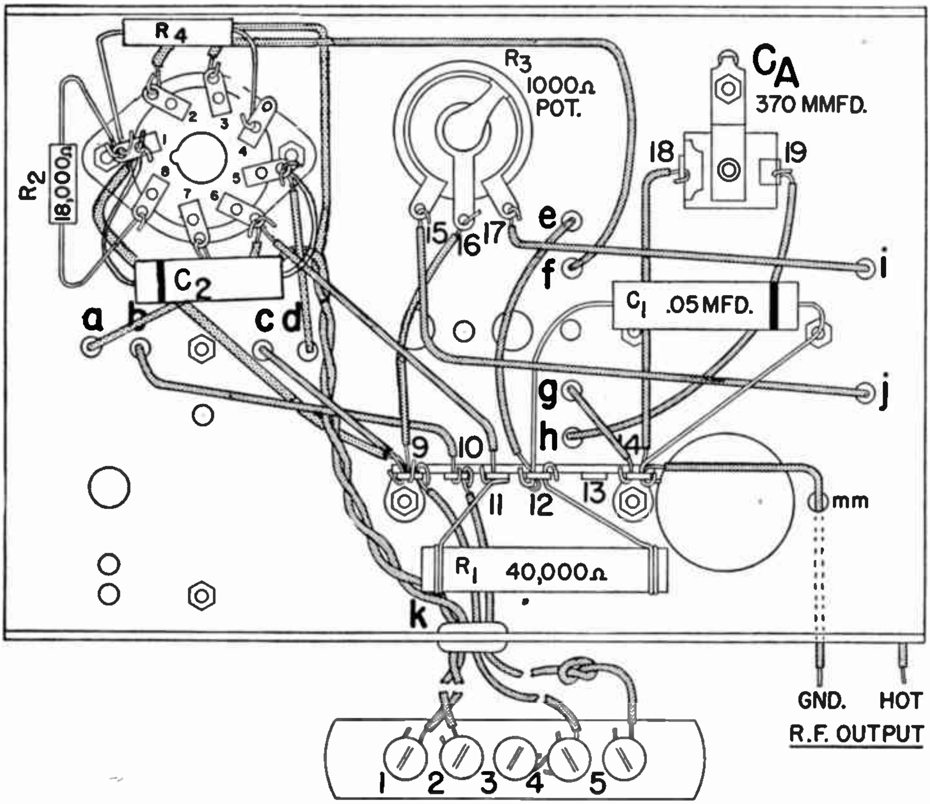


FIG. 33. Bottom view of the r.f. chassis, showing how the completed plate-modulated r.f. oscillator should appear after assembly has been completed. Connections on top of the chassis for this plate-modulated oscillator are the same as for the grid-modulated oscillator except for the r.f. output leads, and consequently the top view in Fig. *30* can be used as a guide for building this plate-modulated r.f. oscillator, if desired.

terminal of the audio transformer, running the wire through chassis hole *b*.

k. Connect terminal *19* to the *green* terminal of the s.g. coil, running the wire through hole *h*.

l. Connect terminal *14* to terminal *18* of trimmer condenser C_A.

m. Connect terminal *14* to the *black* terminal of the s.g. coil, running the wire through hole *g*.

n. Connect terminal *3* to the *blue* terminal of the s.g. coil, running the wire through hole *f*.

o. Connect terminal *12* to the *red* terminal of the s.g. coil, running the wire through hole *e*.

p. Connect socket terminal *6* to terminal *11*.

q. Connect a 40,000-ohm resistor between terminals *11* and *12*.

r. Connect a .05-mfd. condenser between terminals *12* and *14*.

s. Connect terminal *15* to the *gray* terminal of the s.g. coil, running the wire through hole *j*.

t. Connect terminal *17* to the *yellow* terminal of the s.g. coil, running the wire through hole *i*.

u. Connect an 8-inch length of hook-up wire to terminal *14*, bring this wire up through chassis hole *mm*, and leave the wire projecting above the chassis to serve as the grounded r.f. output terminal (terminal lug *14* is grounded to the chassis through its mounting screw).

v. Connect a 6-inch length of hook-up wire to the *yellow* terminal of the s.g. coil, to serve as the hot r.f. output lead. Tie a knot in this lead.

w. Connect a 40,000-ohm resistor between the *green* and *unmarked* terminals of the s.g. coil.

x. Connect a .01-mfd. condenser between the *green* and *unmarked* terminals of the s.g. coil, so that it is in parallel with the 40,000-ohm resistor.

y. Connect the grid clip lead to the *unmarked* terminal of the s.g. coil. Insert the 6F8G tube in its socket, then place the grid clip on the top cap of the tube.

z. Connect your completed plate-modulated r.f. oscillator to the power pack output terminals (twisted leads on output terminals *1* and *2*, knotted lead on terminal *5* and the other lead on terminal *4*).

Testing Instructions. Prepare your N.R.I. Tester for use as an aural indicator (for listening to audio signals), and connect its clips to the r.f. output leads of your plate-modulated r.f. oscillator as shown in Fig. *35* (polarity does not matter). Turn on the power pack and the N.R.I. Tester, and listen for the modulation tone in the headphone after the apparatus has warmed up.

Adjust the position of the 1,000-ohm potentiometer over its entire range, and note the effect of the potentiometer setting upon the level (signal strength) of the audio modulation.

Adjust trimmer condenser C_A and note that changing the frequency of the r.f. signal in this manner has some effect upon the level of the audio modulation, but that the modulation exists for all settings.

Discussion: In this experiment, we use essentially the same type of r.f. oscillator circuit and the same type of a.f. oscillator circuit in all three steps, and introduce the a.f. signal into the r.f. oscillator circuit at three

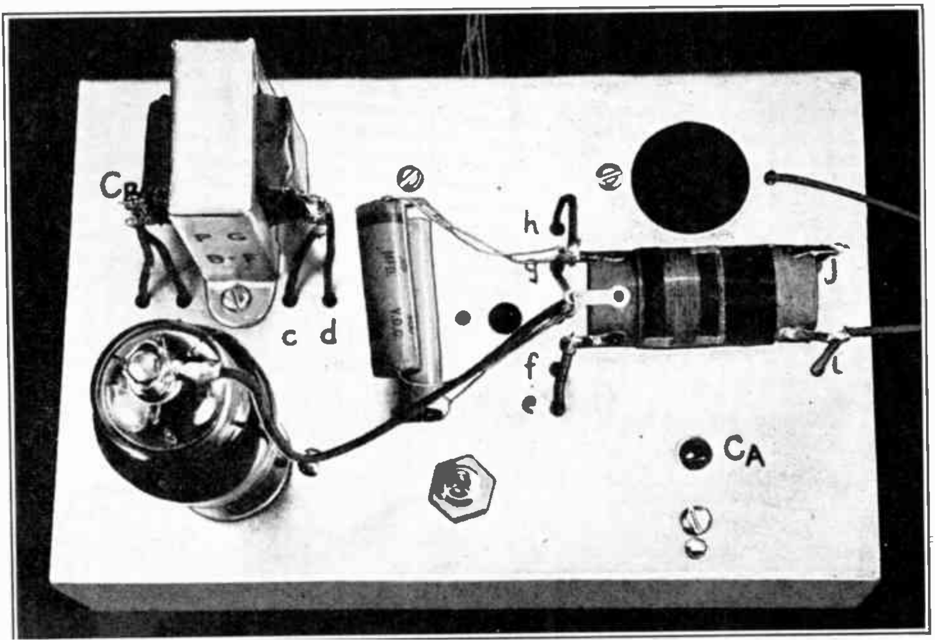


FIG. 34. Top view of completed plate-modulated r.f. oscillator, as assembled for Experiment 50 and for future experiments.

different points: *in the grid circuit; in the cathode lead; in the plate circuit.* In each case, we used the N.R.I. Tester as an aural indicator; the tube in the tester rectifies the modulated r.f. signal so that the r.f. and a.f. signals can be separated, and the phone unit then makes the a.f. signal audible.

The fact that we obtain the output or test signal from the third winding of the signal generator coil is definite proof that we are producing an audio-modulated r.f. signal rather than an audio signal alone. This third winding is inductively coupled to the other windings through an air core, and we know that only a negligible amount of a.f. signal can be transferred from one winding to another through an air core. This means that r.f. energy is being transferred to this third winding. The fact that we hear an audio tone proves that this r.f. energy is modulated with the audio signal.

With the grid-modulated circuit employed in Step 1, the parts within the shaded area in the schematic circuit diagram in Fig. *28* form an audio oscillator of the tuned grid type. Condenser C_1 and resistor R_1 form the coupling circuit through which the a.f. oscillator feeds into the r.f. oscillator, and the remaining parts in this diagram form an r.f. oscillator which is likewise of the tuned grid type. The a.f. signal voltage developed between the plate terminal of the a.f. oscillator tube and the chassis is applied through C_1 and R_1 to the grid terminal (top cap) of the r.f. oscillator and the chassis, so that a.f. current flows through grid resistor R_G and develops across this resistor an a.f. voltage which alternately increases and decreases the automatic C bias voltage across this resistor. As a result, we have both r.f. and a.f. voltages acting upon the grid of the r.f. oscillator triode section, and the signal current flowing through the plate coil is an r.f. signal with audio modulation. This induces in the third winding of the signal generator coil the modulated r.f. signal which you listen to with the aural indicator.

Both C_1 and R_1 in the coupling circuit limit the flow of a.f. current along this path. The larger the capacity value of C_1 and the smaller the ohmic value of R_1, the more a.f. voltage there will be applied to the grid circuit of the r.f. oscillator. On the other hand, increasing the capacity of C_1 or reducing the resistance of R_1 loads both the r.f. and a.f. oscillators, reducing their output voltages. If this loading acts unequally upon the two oscillators, excessive loading may make it impossible to secure the desired percentage of modulation, and may even make one oscillator stop functioning.

With the cathode-modulated circuit used in Step 2 and shown in Fig. *31* the parts within the shaded area again form the audio oscillator. If C_1, R_1, C_B, and R_5 were omitted and the cathode (terminal *4*) of the other triode section were grounded, the remaining parts would form an unmodulated tuned grid r.f. oscillator. With these four parts in the circuit, both the a.f. current fed through C_1 and R_1 and the plate current of the r.f. oscillator triode section flow through R_5. Thus, we have both the normal C bias voltage and an a.f. voltage developed across R_5; both of these voltages act upon the grid of the r.f. section, thereby creating a modulated r.f. signal.

The capacity value of C_B must be such that the reactance of this condenser at the r.f. output frequency will be negligible with respect to the ohmic value of R_5. We also have the requirement that at audio frequencies the reactance of this con-

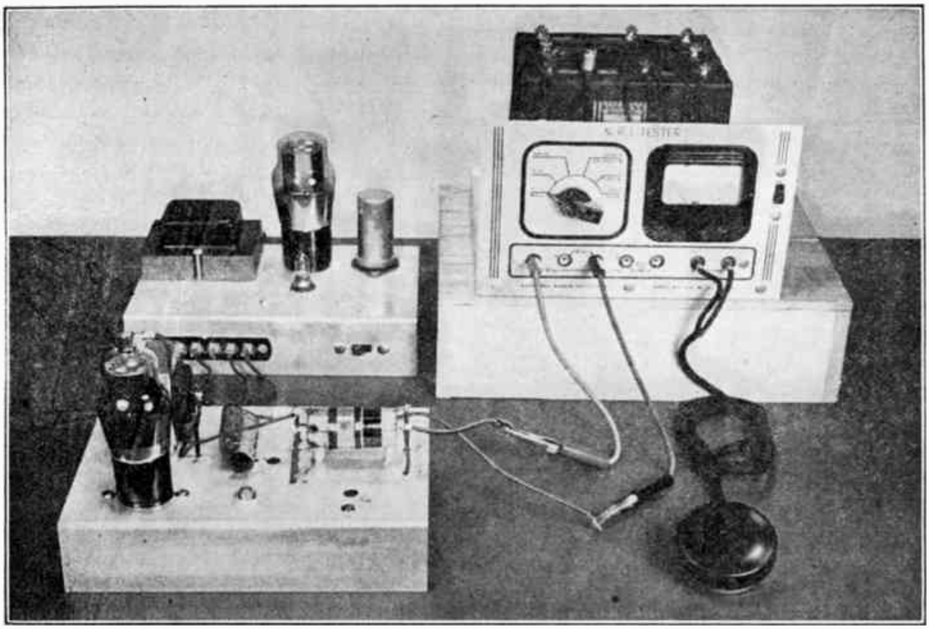


FIG. 35. In this view, all connections have been made between the plate-modulated r.f. oscillator, the power pack and the N.R.I. Tester in preparation for an audio listening test.

denser must be as large as possible; this is the reason for using only a 370-mmfd. condenser for C_B.

With this cathode-modulated circuit C_1, R_1 and R_5 control the percentage of modulation and at the same time affect the output of each oscillator circuit through their loading effects.

With the plate-modulated r.f. oscillator circuit used in Step 3 and shown in Fig. *32*, parts within the shaded area again represent the audio oscillator, and all other parts form the r.f. oscillator. Note that the plate voltage of the r.f. oscillator tube is applied through the primary winding of the audio transformer and through 40,000-ohm resistor R_1. Condenser C_1 is high enough in value (.05 mfd.) to by-pass all r.f. signals to the chassis and thus prevent r.f. from entering the audio circuit. At the same time R_1 and C_1 together act as a resistance-capacity filter for audio signals, allowing the desired fundamental audio frequency to pass through but suppressing the higher audio harmonics which might otherwise distort the modulation.

When the plate-modulated r.f. oscillator circuit is in operation, both the normal d.c. supply voltage and the a.f. signal developed across the primary of the audio transformer act in series upon the plate of the r.f. oscillator triode section. The resulting increases and decreases in the d.c. plate voltage at an audio rate cause the amplitude of the r.f. plate current to rise and fall at an audio rate, thereby giving the desired amplitude modulation.

In this plate-modulated circuit, lowering the resistance of R_1 makes the r.f. oscillator give higher r.f. output, because this raises the d.c. plate voltage of the oscillator tube. At the same time, lowering R_1 places a greater load upon the audio oscillator, for R_1 acts through the plate-cathode path of the r.f. tube to shunt the a.f. oscillator output circuit. An excessively low value for R_1 would make the audio voltage so low that the percentage of modulation would be very nearly zero and no audio signal would be heard with an aural indicator.

Instructions for Report Statement No. 50. The r.f. output voltage value of your modulated r.f. oscillator can readily be measured with the N.R.I. Tester. Furthermore, since this value will tell us whether you have assembled this final project in this manual correctly, you are asked in Report Statement No. 50 to give the r.f. output voltage value you measured between the two r.f. output leads while using the *V* range of the N.R.I. Tester, with the 1,000-ohm potentiometer on the oscillator chassis adjusted for maximum r.f. output, and with trimmer condenser C_A set one turn off from maximum capacity. The headphone should be removed from the *PHONE* jacks for this measurement. For your information, the N.R.I. value for this measurement was 3 volts; your own value should be within 1 volt of this, but need not necessarily be the same.

Important: After completing all measurements for this experiment, turn off the power pack and the N.R.I. Tester, remove the test probes from the N.R.I. Tester, then set aside all apparatus carefully in a safe place until you receive the next manual in your Practical Demonstration Course and are ready to start the next group of ten experiments. Do not discard any parts or wires whatsoever until you have completed the entire N.R.I. Course.

Detach by Cutting Along This Line. Do Not Tear Off.

INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 31 TO 40

4 RK-AC

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

A COURSE IN PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

A PLAN FOR TODAY

I WILL AWAKEN:	With a smile brightening my face; with reverence for this new day in my life and the opportunities it contains.
I WILL PLAN:	A program which will guide me successfully past the many temptations and distractions of a busy day and bring me one step closer to my goal of success.
I WILL WORK:	With my heart always young and my eyes open so that nothing worth while shall escape me; with a cheerfulness that overcomes petty irritations and unpleasant duties; with the purpose of my work always clearly in mind.
I WILL RELAX:	When tired, so as to accumulate fresh energy and live long enough to enjoy the success my work will bring.
I WILL PLAY:	With the thought that today is my day, never to be lived over again once it is ended; with relaxation and pure enjoyment as the only purposes of play; putting work and worldly worries out of mind for this short portion of my day.
I WILL RETIRE:	With a weariness that woos sleep; with the satisfaction that comes from a day well lived, from work well done.
I WILL SLEEP:	Weary but content; with tomorrow a vision of hope.

J. E. SMITH

NATIONAL RADIO INSTITUTE
WASHINGTON, D. C.
1950 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 31 to 40

Introduction

THE next ten experiments, as well as later experiments, call for the use of a power pack which will supply a.c. and d.c. voltages having values corresponding to those encountered in actual radio receivers. Before beginning these experiments, you will assemble a power pack with the parts furnished you in Radio Kit 4RK-AC and in previous radio kits.

An a.c. source having some definite voltage and frequency is usually the main source of power for the vacuum tube system in a radio receiver, transmitter or public address system. This a.c. source is usually a wall outlet which is connected to a 115-volt, 50 or 60-cycle power line.

The main a.c. source of power cannot ordinarily be connected directly to vacuum tube circuits, for the requirements of the various tube electrodes are quite different.

Voltage Requirements of A.C. Receivers. First of all, the a.c. line voltage must be reduced to the correct lower a.c. values for heating the filaments of radio tubes. The rectifier tube in the power pack of an a.c. receiver usually requires a separate 5-volt or 6.3-volt a.c. source for its filament, and the rest of the tubes have their filaments connected in parallel to a common 6.3-volt a.c. source. (In older a.c. receivers, you may encounter tubes having 2.5-volt filaments.)

A secondary winding which is provided on the power transformer of an a.c. power pack for stepping down the line voltage to the required filament value is commonly called a *filament winding*. The power transformer which is supplied for your a.c. power pack has two filament windings, one being a 5-volt winding for the rectifier tube in the power pack, and the other being a 6.3-volt winding for the tubes which you will use in your experiments later on. Thus, you will be working with the same filament voltage values used in modern a.c. receivers.

Secondly, the a.c. line voltage must be converted to a high d.c. voltage value having as little a.c. ripple as possible, and various proportions of this maximum d.c. voltage must be distributed to the various grid and plate electrodes in the vacuum tube circuit. As you learned in your regular course, this voltage conversion is accomplished in three steps, by using a power transformer to step up the a.c. line voltage, rectifying the resulting high a.c. voltage with a rectifier tube, then filtering out the ripples in this pulsating d.c. output with a condenser-input filter system.

In addition to the two filament windings already described, the power transformer which is supplied you in Radio Kit 4RK-AC has a center-tapped 750-volt secondary winding which provides the required high a.c. voltage for the vacuum tube rectifier. This winding is commonly called the *high-voltage secondary winding*. The voltage between the center tap and each outer terminal of the winding is about 375 volts.

The a.c. power pack which you will build thus consists essentially of a power transformer, rectifier tube, choke coil and filter condensers, connected exactly like the power packs of a.c. radio receivers.

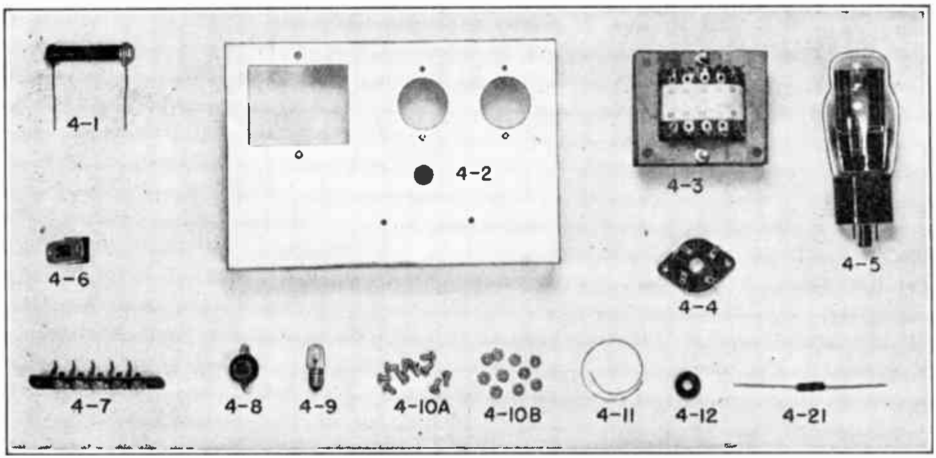


FIG. 1. The parts included in Radio Kit 4RK-AC are pictured above, and are identified in the list below. Some resistors may have a better tolerance (lower percentage tolerance) than that indicated here.

Part No.	*Description*
4-1*	One 50,000-ohm, 3-watt resistor with 20% tolerance (color-coded green, black, orange).
4-2	One cadmium-plated steel chassis bent to shape, with all holes already punched.
4-3	One power transformer for 115 volt, 50 or 60-cycle a.c. power.
4-4	One octal-type tube socket with four terminal lugs.
4-5	One type 5Y3G full-wave rectifier tube.
4-6	One slide-type power switch.
4-7	One 5-terminal, screw-type binding post strip.
4-8	One pilot lamp socket with rubber grommet.
4-9	One 6.3-volt pilot lamp.
4-10A	Ten ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
4-10B	Ten cadmium-plated hexagonal nuts for 6-32 screws.
4-11	One 3-ohm length of nichrome resistance wire.
4-12	One small rubber grommet.
4-21	One 10-megohm, ½-watt resistor with 10% tolerance (color-coded brown, black, blue, silver).

* You may receive a 47,000-ohm, a 50,000-ohm, or a 51,000-ohm resistor as Part 4-1, depending on what we have in stock when we pack your kit. Use whatever value you receive for this part where the 50,000-ohm listed value is called for.

The following parts which were supplied to you in earlier radio kits will be used again in the next ten experiments, so assemble these parts along with the new parts received in Radio Kit 4RK-AC.

Part No.	*Description*
1-8D	One ⅜-inch soldering lug.
1-16	One 18,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, gray, orange, silver).
3-2A & B	Two .25-mfd., 400-volt paper condensers.
3-3	One dual 10-10-mfd., 450 working volts electrolytic condenser with bakelite mounting piece.
3-4	One 200-ohm, 1-watt resistor with 20% tolerance (color-coded red, black, brown).
3-5A	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red, silver).
3-6A, B, C & D	Four 40,000-ohm, 3-watt resistors with 20% tolerance (color-coded yellow, black, orange).
3-10	One 10-henry choke coil with 25-ma. current rating.
3-11	One 5-foot power line cord with attached outlet plug.

Power Pack Experiments. With your a.c. power pack, you will demonstrate that the output voltage drops and ripple output goes up as the load on the power pack is increased. The first effect, in which the d.c. output voltage drops with load, is known as the *voltage regulation* of a power pack.

Your power pack is normally connected for full-wave rectification and a condenser-input filter system. You will disconnect one filter condenser to secure choke input, then disconnect one plate lead of the rectifier tube to secure half-wave rectification, and check the performance of the power pack with your N.R.I. Tester in each case. You will insert resistors to duplicate the practical conditions in which electrolytic condensers become defective, and make measurements which will enable you to recognize these same defects in actual receivers.

We have mentioned here only a few

of the highly practical power pack experiments presented in this manual. By the time you have completed Experiment 40, you will have a thoroughly practical understanding of power packs.

Contents of Radio Kit 4RK-AC

The parts included in your Radio Kit 4RK-AC are illustrated in Fig. *1* and listed in the caption underneath. Check off on this list the parts which you received, to be sure you have all of them. Do not destroy any of these parts until you have completed your entire N.R.I. course, for many of the parts will be used over and over again in later experiments.

IMPORTANT: If any part in your Radio Kit 4RK-AC is obviously defective or has been damaged during shipment, please return it to the Institute *immediately* for replacement.

Instructions for Assembling the A.C. Power Pack

Step-by-step instructions for assembling the a.c. power pack will now be given. Follow through these instructions slowly and carefully, doing the very best work of which you are capable, for you will use this power pack during the remainder of your practical demonstration course, and will want your unit to show professional workmanship in every soldered joint. To make sure that you do not miss any of the steps in the assembly procedure, make a check mark alongside each completed step as you go along.

The schematic circuit diagram for this power pack is presented in Fig. *2* for reference purposes. Later, you will be able to assemble radio apparatus from diagrams like this alone, but at the present stage in your course of training, we still recommend that you follow the pictorial diagrams which are presented in this manual to show each stage in the assembly procedure. Remember that we are ready to help you with advice if you should encounter any difficulty in assembling this power pack or in understanding the instructions.

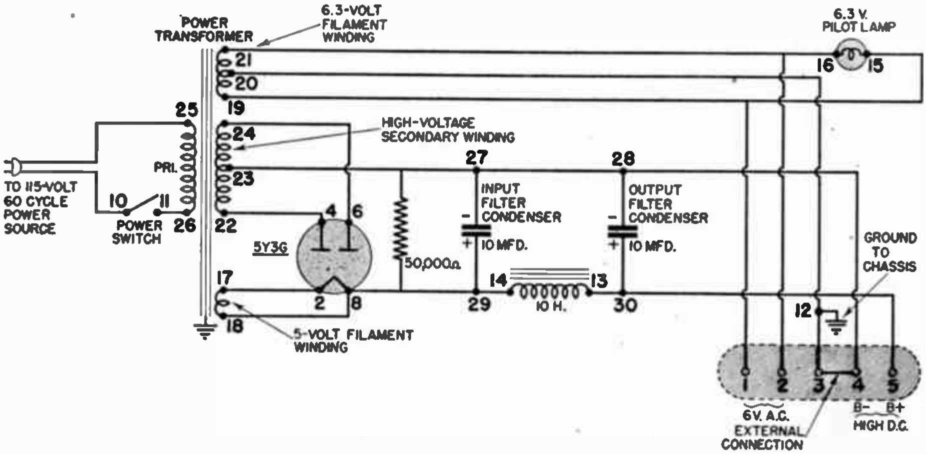


FIG. 2. Schematic circuit diagram for the a.c. power pack which you build before beginning the experiments in this manual. The terminals on this schematic diagram are numbered to correspond with the terminals shown on the semi-pictorial diagrams in Figs. *5* and *8*.

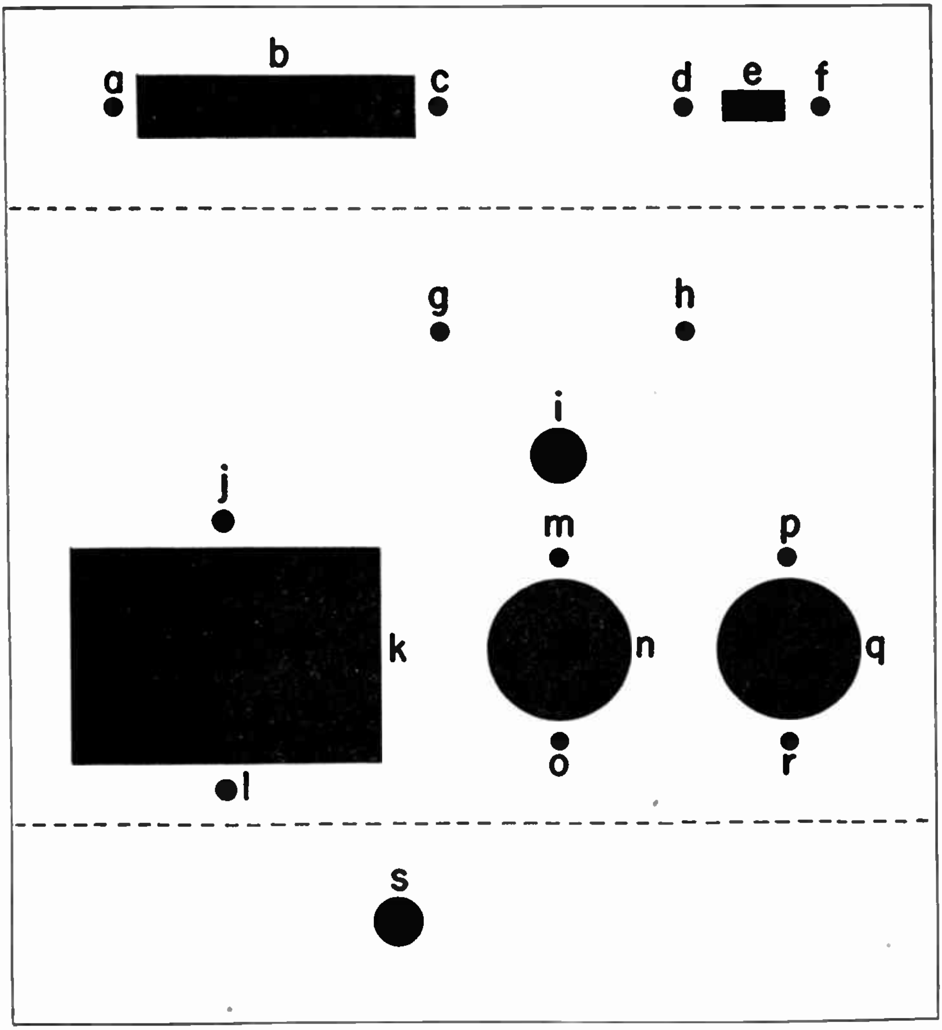


FIG. 3. Chassis layout diagram for the a.c. power pack, drawn to show what you would see if you looked at the bottom of the chassis while it was a flat sheet (before bending the sides). The holes are lettered here merely for your convenience in locating on your own chassis the correct mounting holes for the various parts; do not mark the holes in this manner on your chassis, for this diagram is entirely sufficient for assembly purposes.

Mounting the Parts on the Chassis

✓ *Step 1. To prepare for the assembly of the power pack,* place before you the following parts:

50,000-ohm resistor (Part *4-1*).
Cadmium-plated steel chassis (Part *4-2*).
Power transformer (Part *4-3*).
Octal-type tube socket (Part *4-4*).
Type 5Y3G rectifier tube (Part *4-5*).
Slide-type power switch (Part *4-6*).
Five-terminal screw-type binding post strip (Part *4-7*).
Pilot lamp socket with grommet (Part *4-8*).
Pilot lamp (Part *4-9*).
Ten ¼-inch binder-head machine screws (Part *4-10A*) with ten hexagonal unts (Part *4-10B*).
Rubber grommet for power line cord (Part *4-12*).
⅝-inch soldering lug (Part *1-8D*).
Dual 10-10-mfd. electrolytic condenser with bakelite mounting piece (Part *3-3*).
Ten-henry choke coil (Part *3-10*).
Power line cord with plug (Part *3-11*).

✓ *Step 2. To mount in hole s the grommet for the power line cord,* place the chassis before you in such a position that the holes correspond with the chassis layout diagram in Fig. *3*. Hole *s* should now be near the center of the side closer to you. Take the rubber grommet (Part *4-12*) and squeeze it into an oval shape while holding it with the thumb and forefinger of your right hand. Now place the grommet in hole *s* in the manner shown in Fig. *4*, with the chassis fitting into the groove in the grommet. Carefully push the remainder of the grommet into this hole with your fingers until half the grommet is on each side of the chassis, with the chassis fitting into the rubber groove in the grommet at all points. This grommet will now have the position shown in Fig. *5*.

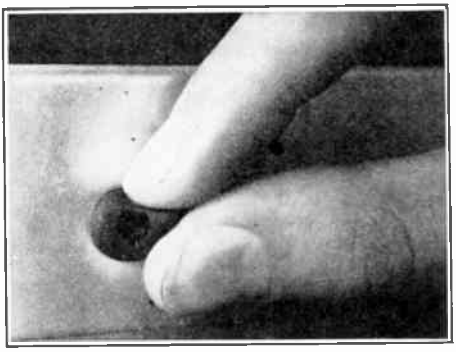


FIG. 4. Squeeze the grommet for the power line cord between your thumb and forefinger in the manner shown here while forcing it into hole *s* in the side of the chassis. This grommet can be placed in position with your fingers; it may take a little time at first, but you will soon get the "knack" of doing this radio job.

✓ *Step 3. To mount the pilot lamp socket in hole i on the chassis,* first remove the large rubber grommet from the pilot lamp socket (Part *4-8*). Squeeze this grommet into an oval shape while holding it between the thumb and forefinger of your right hand, and work the grommet into hole *i* (see Fig. *3*) on the chassis in exactly the same manner as described in Step 2 for the power line grommet. To force the pilot lamp socket itself up through the grommet which you have now inserted in hole *i*, grasp the socket near its terminal lugs with your fingers, push the threaded part gently into the grommet from the bottom of the chassis as far as it will go without forcing, turn the socket in a clockwise direction until one of the lugs touches the grommet, then rotate the socket just enough farther to line up the lugs parallel to the sides of the chassis. When looking at the bottom of the chassis, the pilot lamp socket will now appear as shown in Fig. *5*.

✓ *Step 4. To mount the electrolytic condenser on the chassis,* take the bakelite mounting piece for this condenser, and hold it against the *top* of the chassis over holes *p*, *q* and *r* in such a manner that the slots have the positions shown in Fig. *5*. Bolt the piece to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*) inserted in holes *p* and *r*, with the screw heads above the chassis.

Now take the electrolytic condenser (Part *3-3*) and insert its lugs in the slots of the bakelite mounting piece from the top of the chassis in such a

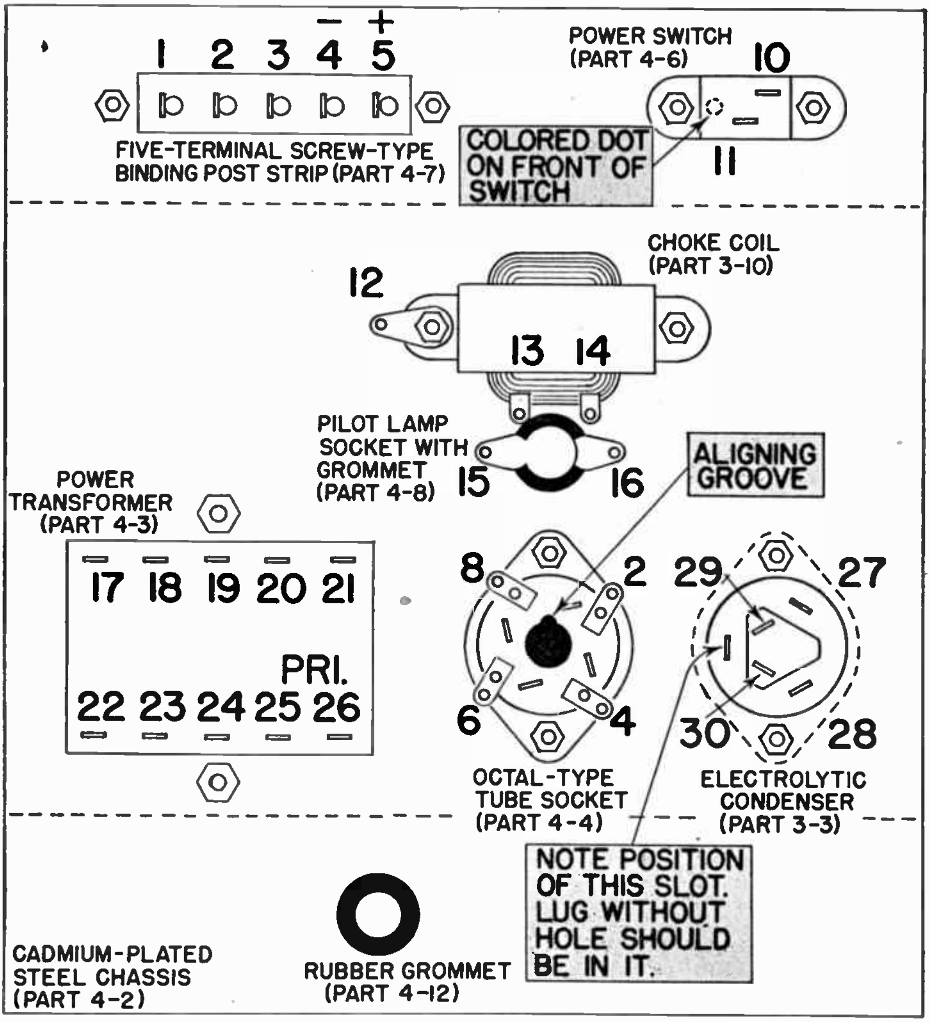


FIG. 5. Bottom view of chassis with sides spread out, showing exact positions of all parts which are mounted directly on the chassis, and showing positions of all numbers which you are to place on the chassis and on the parts with metal-marking crayon. The dotted lines indicate the positions of the bends in the chassis.

way that *the outer lug which has no hole* in it will be *next to hole n* on the chassis. If this condenser is inserted correctly, the two large inside lugs at the bottom of the condenser will be almost in line with the condenser mounting screws, as indicated in Fig. *5*.

With one hand holding the condenser in position against the top of the chassis, take a pair of ordinary pliers and twist each of the three outer lugs on the condenser a *small* amount, in the manner shown in Fig. *6*. This will hold the condenser securely in position on its mounting piece.

Step 5. To mount on the chassis the socket for the rectifier tube, take the octal-type tube socket (Part *4-4*) and hold it against the *bottom* of the chassis over holes *m, n* and *o* in such a way that the aligning groove in the socket is next to the pilot lamp socket (see Fig. *5*). Fasten the socket to the chassis in this position with two machine screws and nuts (Parts *4-10A* and *4-10B*), keeping the screw heads above the chassis. (Although the rectifier tube which goes into this socket has five prongs, only four of them are used in this power pack circuit. Prong *1* on the tube is a dummy, used only in special applications which require shielding the tube and grounding the shield to the chassis through this prong.)

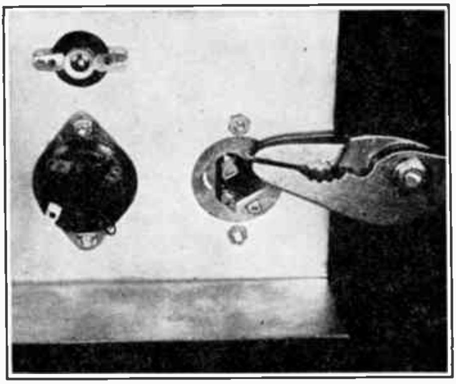


FIG. 6. This illustration shows the correct position of the bakelite mounting piece on the chassis, with the electrolytic condenser in position, and also shows how the outer lugs of the condenser are twisted with pliers to fasten the condenser unit to the bakelite mounting piece. Two of the lugs have already been twisted, and the last one is being twisted in this illustration.

Step 6. To mount the power switch on one side of the chassis, take the slide-type switch (Part *4-6*), set the sliding button to the position in which the colored dot shows, hold the switch against the *inside* of the chassis over holes *d, e* and *f* in such a position that the colored dot is nearer to the center of the chassis (nearer to hole *d*), then fasten this switch to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*), keeping the heads of the screws on the outside of the chassis.

Step 7. To mount the terminal strip on the chassis, take the five-terminal screw-type binding post strip (Part *4-7*) and hold it against the *outside* of the chassis over holes *a, b* and *c* in such a manner that the numbers on the fiber strip are below the screws when the chassis is in its normal upright position, as shown in Fig. 7. Fasten the strip to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*), keeping the heads of the screws on the outside of the chassis.

Step 8. To mount the choke coil on the chassis, take the 10-henry choke coil (Part *3-10*) and hold it against the *bottom* of the chassis in such a way that its mounting tabs are over holes *g* and *h* and its terminal lugs are next to the pilot lamp socket, as shown in Fig. *5*. Fasten the choke coil to the chassis with two machine screws and nuts (Parts *4-10A* and *4-10B*). Keep the screw heads above the chassis, and place a ⅝-inch soldering lug (Part *1-8D*) under the nut for hole *g*, as shown in Fig. *5*.

Step 9. To mount the power transformer on the chassis, first take the

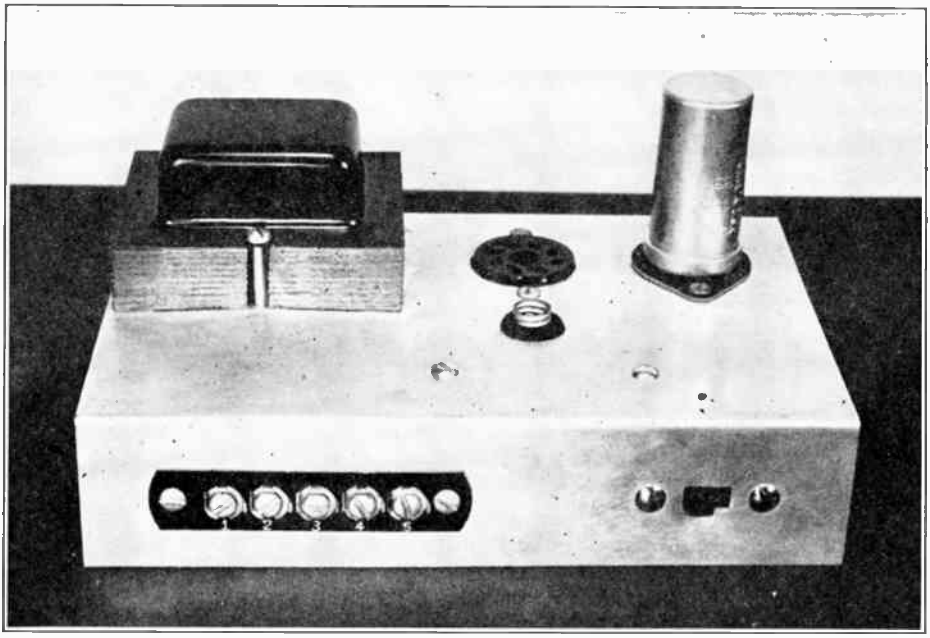


FIG. 7. View of the completed a.c. power pack before the rectifier tube and pilot lamp have been inserted in their sockets.

power transformer (Part *4-3*) and remove the nuts from the two long machine screws which go through the transformer core. Place the transformer on *top* of the chassis over holes *j, k* and *l* in such a way that the numbered terminals will appear in exactly the same position illustrated in Fig. *5*. Now insert the long machine screws through the power transformer mounting holes and through holes *j* and *l* respectively on the chassis. On each screw underneath the chassis, place a nut, and tighten the screws with a screwdriver, holding the nuts with ordinary pliers.

This completes the mounting of the large parts on the chassis. The top of the chassis should now appear as shown in Fig. *7*.

Step 10. To identify the terminals of the parts now mounted on the chassis, place alongside each terminal with metal-marking crayon the number indicated for that terminal in Fig. *5*. Place these numbers as nearly as possible in the positions shown in Fig. *5*. If the power transformer terminals are not marked, place the numbers on the fiber insulating material at the bottom of the transformer, or on the chassis beside the terminals. The choke coil lug numbers should be placed on the choke coil. All other numbers go directly on the chassis, as close as possible to the terminals in question. Place a — sign near output terminal *4*, and place a + sign near output terminal *5 on both sides* of the chassis.

Check your numbering carefully against Fig. *5* after you are finished, for errors in numbering will cause errors in wiring. Finally, check the terminal strip to be sure each lug is numbered the same on both sides of the chassis.

Step 11. To connect together the various terminals with hook-up wire, follow carefully the detailed step-by-

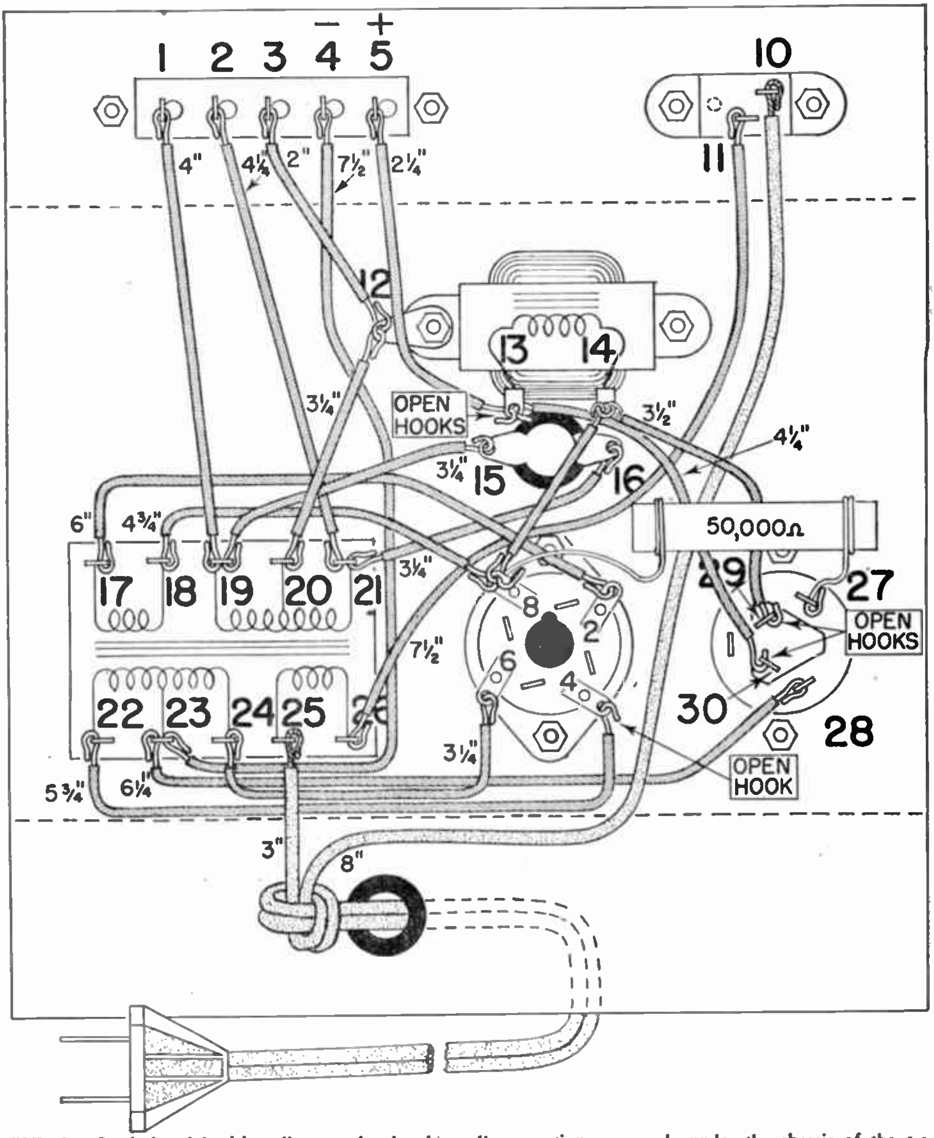


FIG. 8. Semi-pictorial wiring diagram showing how all connections are made under the chassis of the a.c. power pack. The sides of the chassis have been flattened out for clearness, but the wire lengths specified on this diagram are correct for the actual chassis.

step instructions which will now be given. Be particularly careful to make *temporary* soldered joints where specified. Use rosin-core solder (supplied in a previous kit) for all joints, and use *red* push-back hook-up wire throughout. Do not solder a joint until told to do so, for premature soldering will make it difficult for you to get additional wires into the hole in the lug. Use the semi-pictorial diagram in Fig. *8* and the photographic illustration in Fig. *9* as your guides for positioning the wiring.

Since the five terminals on the screw-type terminal strip are the output terminals of the power pack, we will refer to these terminals as the *output terminals*, to distinguish them from tube socket terminals having the same numbers.

✓ *a.* Connect output terminal *4* to transformer terminal *23* with a 7½-inch length of hook-up wire, making permanent hook joints but soldering only terminal *4*.

✓ *b.* Connect transformer terminal *23* to electrolytic condenser lug *28* with a 6¼-inch length of hook-up wire, making permanent hook joints and soldering both terminals this time.

✓ *c.* Connect transformer terminal *17* to socket terminal *2* with a 6-inch length of wire, making permanent hook joints and soldering both terminals.

✓ *d.* Connect transformer terminal *18* to socket terminal *8* with a 4¾-inch length of wire, making permanent hook joints but soldering only terminal *18*.

✓ *e.* Connect transformer terminal *21* to pilot lamp socket terminal *16* with a 3¼-inch length of wire, making permanent hook joints but soldering only terminal *16*. Examine terminal *16* carefully after soldering, to be sure no part of this joint touches the chassis.

✓ *f.* Connect transformer terminal *21* to output terminal *2* with a 4¼-inch length of wire, making permanent hook joints and soldering both terminals.

✓ *g.* Connect transformer terminal *19* to pilot lamp socket terminal *15* with a 3¼-inch length of wire, making permanent hook joints but soldering only terminal *15*. Be sure the wire does not touch the chassis.

✓ *h.* Connect transformer terminal *19* to output terminal *1* with a 4-inch length of wire, making permanent hook joints and soldering both terminals.

✓ *i.* Connect transformer terminal *20* to grounding terminal *12* with a 3¼-inch length of wire, making permanent hook joints but soldering only terminal *20*.

✓ *j.* Connect grounding terminal *12* to output terminal *3* with a 2-inch length of wire, making permanent hook joints and soldering both terminals.

✓ *k.* Connect transformer terminal *24* to socket terminal *6* with a 3¼-inch length of wire, making permanent hook joints and soldering both terminals.

✓ *l.* Connect transformer terminal *22* to socket terminal *4* with a 5¾-inch length of wire, making a *temporary* hook joint on socket terminal *4* and a permanent hook joint on terminal *22*. Solder both terminals.

✓ *m.* Connect transformer terminal *26* to power switch terminal *11* with a 7½-inch length of wire, making permanent hook joints and soldering both terminals. Run this wire between the tube and pilot lamp sockets, as shown in Fig. *8*.

✓ *n.* Connect choke coil terminal *13* to output terminal *5* with a 2¼-inch length of wire, making a *temporary* hook joint at terminal *13* and a permanent hook joint on terminal *5*. Solder only terminal *5*.

✓ *o.* Connect choke coil terminal *13* to electrolytic condenser terminal *30* with a 4¼-inch length of wire, making *temporary* hook joints in both cases and soldering both terminals.

✓ *p.* Connect choke coil terminal *14* to electrolytic condenser terminal *29* with a 3½-inch length of wire, making a *temporary* hook joint at terminal *29* and a permanent hook joint at terminal *14*, but solder only terminal *29*.

✓ *q.* Connect choke coil terminal *14* to socket terminal *8* with a 2¼-inch length of hook-up wire, making per-

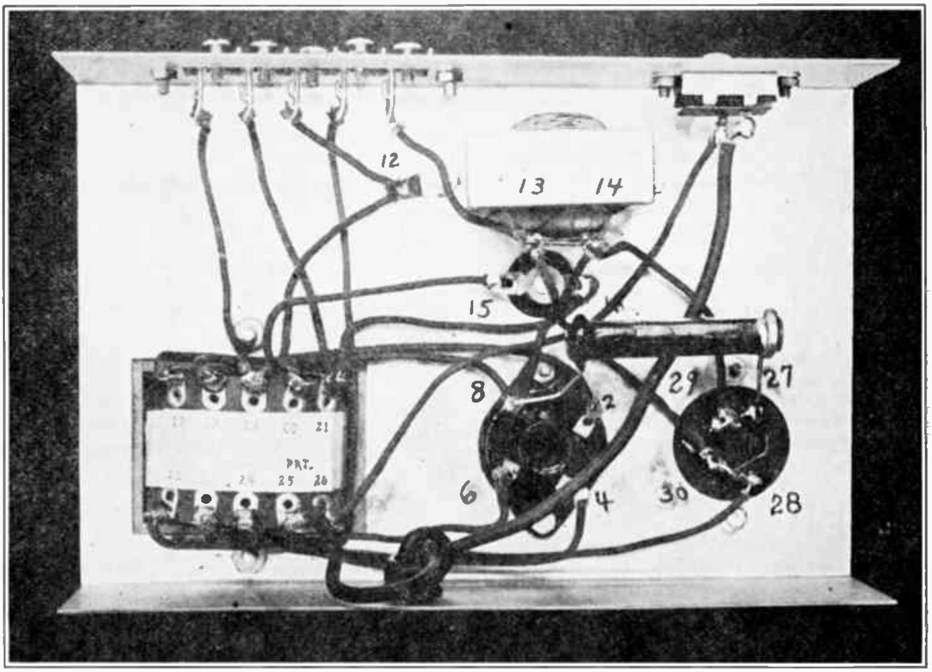


FIG. 9. Your a.c. power pack should look essentially like this under the chassis when you have completed all wiring. The positions of the various wires are not particularly important as long as they go to the proper terminals, hence some of the wires shown in this view may be in slightly different positions from corresponding wires in Fig. 8.

manent hook joints in both cases but soldering only terminal *14*.

r. Connect the 50,000-ohm resistor (Part *4-1*) between socket terminal *8* and electrolytic condenser terminal *27*, after first shortening the resistor leads so they are each about one inch long. Make permanent hook joints and solder both terminals.

s. Insert the free end of the power line cord through the rubber grommet which is in hole *s*, starting from the outside. Pull at least a foot of the cord through the grommet, then tie a simple knot in the cord in the manner shown in Fig. *8* so that there are 8 inches of wire left beyond the knot. Split this 8-inch length down to the knot by pulling the two rubber-covered wires apart with your fingers. Connect one 8-inch length of wire to power switch terminal *10* by means of a permanent soldered hook joint, after first spreading out the strands of wire and scraping them lightly with the blade of a pocket knife, then twisting the strands tightly together so you can insert them through the hole in the lug. Run the wire between the tube socket and the electrolytic condenser, and go under the 50,000-ohm resistor and the two electrolytic condenser leads, as indicated in Fig. *8*.

t. Shorten the other 8-inch length of wire to a length of 3 inches, and remove about half an inch of insulation from this shortened end either by cutting or squeezing. Be careful not to nick or cut any of the copper strands when doing this. Spread out the strands and clean by scraping, then twist them together and connect this shortened end of wire to transformer terminal *25* by means of a permanent soldered hook joint.

Step 12. To make continuity tests with the ohmmeter in your N.R.I. Tester for the purpose of checking the correctness of connections in the a.c. power pack, first prepare the ohmmeter for resistance measurements according to the "OHMMETER MEASUREMENT" instructions given in this manual.

Whenever a measurement with the N.R.I. Tester is called for in the experiments, you are expected to refer to and follow the instructions given for that type of measurement in the "OPERATING INSTRUCTIONS FOR N.R.I. TESTER" boxes which appear in this manual.

In the following continuity tests, failure to obtain the specified result indicates either a mistake in wiring or a defective part. If no mistake in wiring can be found by checking against the semi-pictorial circuit diagram in Fig. *8*, check each individual part in the circuit under consideration. If you are certain that one of the parts is defective, return it to National Radio Institute immediately.

a. Insert the rectifier tube in its socket but leave out the pilot lamp. Set the power switch to the *OFF* position (the red dot alongside the sliding button shows when this switch is *ON* but not when it is *OFF*.)

b. Check continuity between the prongs of the power cord plug with the *MEG.* range by placing the red clip on one prong, placing the black clip on the other prong, and reading the resistance in megohms directly on scale *R*. The reading should be above 50 megohms (while switch is *OFF*).

c. Leave the clips on the power cord plug prongs, but *do not* insert the plug in an outlet. Snap *ON* the switch on the power pack chassis so that the red dot shows. The meter should now read zero on scale *R*. Leave the switch in the *ON* position.

Do not touch the metal parts of the test clips with your fingers while reading resistance values on the meter; this would place the resistance of your body in parallel with that being measured, resulting in erroneous readings when checking for grounds or measuring high resistance values.

d. To check the resistance of the primary winding of the power transformer, set the selector switch to *10 × R*, leave the clips on the prongs of the power cord plug, read the meter on scale *R*, and multiply the reading by 10 to get the resistance in ohms of the circuit under test. This should be between 10 and 20 ohms, and will consist essentially of the resistance of the primary winding of the transformer.

e. To check continuity between the power plug prongs and the chassis, set the selector switch of the N.R.I. Tester at *MEG.*, place the black clip on the power pack chassis, and place the red clip in turn on each prong of the power cord plug. The meter reading should be higher than 50 megohms in each case.

f. To make sure that the high-voltage secondary circuit of the power transformer and the electrolytic condenser housing are not grounded, place the black clip on the chassis, place the red clip in turn on output terminal *4*, on socket terminal *4* and on socket terminal *6*, and measure the resistance in each case with the *MEG.* range of the N.R.I. Tester. A reading of 50 megohms or higher on scale *R* should be obtained in each case.

g. To make sure that the rectifier tube filament circuit is not grounded, place the black clip on the chassis, place the red clip on socket terminal *8*, and measure the resistance with the *MEG.* range. The meter should read higher than 50 megohms on scale *R*. Move the red clip to socket terminal *2*. Again the meter should read higher than 50 megohms.

OHMMETER MEASUREMENTS

1. Check the general calibration of your NRI Tester as instructed on page 14 of this Instruction Manual, and then plug the red test lead probe into the +R jack, plug the black test lead probe into the right-hand R jack, and set the selector switch at *Meg.*
2. To check the ohmmeter zero adjustment, hold the test lead clips together and turn the tester ON. The meter pointer should now indicate *O* at the right end of scale R. If it does not, adjust the tester potentiometer until it does so. *Do not, however, change the setting of the knob at the back of the meter.*
   IMPORTANT: Make the ohmmeter calibration as quickly as possible and then separate the test leads to prevent exhausting your batteries any more than absolutely necessary.
   Before you make any ohmmeter tests, be sure to turn power OFF any equipment (preferably by removing the power cord plug) you want to check.
3. Although you can start your ohmmeter measurements using any range of the tester, it is usually most convenient to start with the *10,000 × R* range. Place the test lead clips on the terminals between which resistance is to be measured, being careful not to touch the metal part of the clips with your hands. Disregard polarity (as indicated by the colors of the test clips) unless otherwise instructed. When you check an electrolytic condenser, however, you should *fasten the red test clip to the negative terminal* of the condenser, and *connect the black test clip to the positive terminal* of the condenser.
4. On the *Meg.* range, the R scale is read directly in *megohms.* On the *10,000 × R* range, multiply the R scale reading by 10,000 to get the resistance value in ohms. Resistance values in ohms on the *100 × R* range are obtained by multiplying the meter reading by 100; and on the *10 × R* range, by multiplying by 10.
5. If your first reading when using the *10,000 × R* range is *O*, the resistance value under test may be anything from 0 to 10,000 ohms. To find the actual value, turn to the *lower* ranges and take your reading on the range which gives approximately mid-scale deflection. Actual zero ohms is indicated by a full-scale deflection only when the *10 × R* range is used.
6. If your first test when using the *10,000 × R* range produces only a small deflection of the meter pointer from its normal open circuit position at the left, turn to the *Meg.* range and read the value directly in megohms. If the meter pointer remains at the left end of the R scale when using the *Meg.* range, the circuit or part under test is "open." (Such a circuit or part is often said to have "infinite" resistance).
7. If you found it necessary to turn the tester potentiometer a considerable amount to get zero adjustment when holding the test clips together, use the range which brings the meter pointer into the right half of the scale. Should it be necessary to use the left half of the scale, calibrate the tester at 0 and 3 on scale DC as instructed on page 14 of this manual under the heading "Checking the Calibration."
8. To conserve battery life, turn the tester OFF and remove both test leads just as soon as you finish a series of resistance measurements.

h. To check filter circuit continuity, set the selector switch to *10,000 × R*, then place the red clip on power transformer terminal *23* and place the black clip on socket terminal *8*. The reading should be somewhere between 40,000 and 60,000 ohms. Now move the black clip to output terminal *5*, and again measure the resistance. The reading should again be between 40,000 and 60,000 ohms.

i. To check wiring and continuity of the high-voltage secondary winding on the power transformer, measure the resistance between socket terminals *4* and *6* while using the *100 × R* range of the N.R.I. Tester. You should obtain a reading somewhere between 400 and 700 ohms.

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

CHECKING THE CALIBRATION

Before using the NRI Tester for any series of measurements, check its calibration as follows:

1. **Remove both test probes, set the selector switch at *100×V* and make sure the calibrating clip is on —9C. Turn the power switch ON and tap the meter gently with a finger. The pointer should be exactly at *O* on the DC scale. If it isn't, adjust the knob at the back of the meter as may be necessary to set the pointer at zero. Look squarely at the meter and don't tilt the tester during calibration or operation.**
2. **Now move the calibrating clip from —9C to —7½C and see if the meter reads 1.5 on scale DC. If necessary, adjust the potentiometer on the tester chassis to get this 1.5 reading.**
3. **Recheck the "zero" position again by moving the calibrating clip back to —9C. The calibration procedure described above, and in previous manuals, insures maximum accuracy only over the left half of the meter scale. The right half of the scale can be checked as follows:**
4. **First, hold the calibrating clip on —6C momentarily, and then on —4½C and note the meter reading at each position. The desired readings are 3 and 4.5 respectively on scale DC. The difference between these values and your readings represent the amount of error in this portion of the scale. If greater over-all accuracy is desired over the entire scale, calibrate at *O* and *3* on scale DC by using —9C and —6C respectively.**

***Return the calibrating clip to —9C so that the meter reads zero before beginning your measurements.* Also, check the calibration from time to time during the course of an experiment to be sure accuracy is maintained.**

j. To check continuity and wiring of the 6.3-volt filament supply circuit in the power pack, measure the resistance between output terminals *1* and *2* with the *10 × R* range of the N.R.I. Tester. The reading should be only a fraction of an ohm (essentially zero). If this reading is around 1000 ohms and the reading obtained in Step *12i* is less than 1 ohm, write to us immediately and give your results for this test. Do not go any further with your experiments until you hear from us, if you obtained these reversed readings.

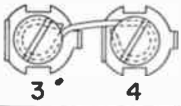


FIG. 10. Method of connecting output terminals *3* and *4* together externally with a 1½-inch length of bare hook-up wire. Note that both hooks are closed, so that the wire will stay in position when the screws are loosened to permit connecting other wires to these terminals.

k. Place the black clip on the chassis, place the red clip on output terminal *3*, and measure the resistance value with the N.R.I. Tester set to the *10 × R* range. The reading should be zero.

Step 13. To check the operation of the power pack, first place the chassis right side up with the terminal strip facing you, make sure that the rectifier tube is firmly in its socket, insert the pilot lamp in its own socket, and push the switch to its *OFF* position (red button does not show).

Next, connect output terminal screws *3* and *4* together externally with a 1½-inch length of bare hookup wire. Do this by forming a hook in one end of the wire, hooking this over screw *4* in a clockwise direction after loosening this screw, closing the hook with pliers, then bending the wire around screw *3* in a clockwise direction and cutting off surplus wire to give an S-shaped connection like that shown in Fig. *10*. Keep these two terminals connected together.

Connect to terminal *3* the ground wire you have provided at your bench for experimental purposes. This ground wire should go to a cold water pipe or other good ground.

Insert the power cord plug into a 115-volt a.c. outlet and turn on the power pack switch. The pilot lamp should now light up, and both filament wires of the rectifier tube should appear dull red when looking straight down on top of the tube. Turn off the power pack.

CAUTION: The ground connection to output terminals *3* and *4* should be made whenever the power pack is used, to avoid getting a shock when touching the power pack chassis.

Do not touch any terminals or parts underneath the chassis of the a.c. power pack while it is in operation. The voltages present at some of these terminals are high enough to give serious electrical shocks.

If neither the pilot lamp nor the rectifier tube glows, check your source of a.c. power by plugging a table lamp or other appliance into the outlet.

Step 14. To check the d.c. output voltage of the power pack when no load is connected, first prepare the N.R.I. Tester according to the "D.C. VOLTAGE MEASUREMENTS" instructions given in this manual.

To measure the d.c. output voltage between terminals *4* and *5*, place the red clip on screw terminal *5* after first loosening this screw about 1/8-inch. Place the black clip on the wire jumper which connects screw terminals *3* and *4*, *being sure that this clip does not touch the red clip.* Turn on the a.c. power pack, then turn on the N.R.I. Tester (be sure it is set to the *100* × *V* range), read the meter on the *DC* scale, and multiply your reading by 100 to get the d.c. output voltage of the power pack in volts. This voltage should be approximately 450 volts if you have assembled the power pack correctly, all parts are in good condition, and you have a normal a.c. line voltage of about 115 volts.

Turn off the power pack while watching the meter. Note that it takes several seconds for the pointer to drop down to zero; this action occurs because the electrolytic filter

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

D.C. VOLTAGE MEASUREMENTS

1. **Plug the black probe into the $-V_{DO}$ jack on the panel, and plug the red probe into the $+V_{DO}$ jack.**
2. **Set the selector switch at *100* × *V*. Always start with the highest d.c. range, in order to prevent overloading of the meter.**
3. **While power is off, place the black test clip on the — terminal of the device whose voltage is being measured, and place the red clip on the + terminal.**
4. **Turn on your apparatus, then turn on the N.R.I. Tester. This order is important, as it prevents high initial voltages from making the meter pointer swing off-scale.**
5. **If the meter reading is low or zero, lower the selector switch setting one range at a time, until you reach the lowest range which does not overload the meter. IMPORTANT: When working with apparatus using heater-type vacuum tubes, wait long enough for the tubes to warm up (about half a minute is sufficient) before lowering the selector switch setting.**
6. **Read the meter on the *DC* scale, and multiply the reading by the correct factor for the range being used. For example, when using range *30* × *V*, multiply the scale reading by 30; when using range *100* × *V*, multiply by 100, etc.**
7. **Turn off the N.R.I. Tester first, then turn off the power source. Pull out the test probes when through using the N.R.I. Tester, to prevent draining of the C battery in case the test clips accidentally touch the tester panel or chassis.**

OVERLOADING OF N.R.I. TESTER

If the pointer of the meter in the N.R.I. Tester vibrates around *0* or reads slightly backwards, but a definite up-scale reading is obtained when you switch to a higher range, this is an indication that the meter was being overloaded on the lower range.

An overload will usually shift the *0* position of the pointer. This condition will be corrected automatically the next time you make an approximately full-scale voltage reading, or can be corrected immediately by lifting up the calibrating clip and touching it momentarily to the —4½C terminal on the battery block. Be sure to return the clip to —9C.

If the pointer seems to stick at the right of the full-scale position, tap the meter lightly with the finger. On voltages near full-scale values, momentum of the pointer carries it farther than the final position, but tapping frees the pointer and often allows you to secure a reading without switching to the next higher range.

condensers hold their charges for that period of time after power is removed. Now turn off the N.R.I. Tester and pull out the power cord plug.

The d.c. output voltage of your power pack will vary slightly with the line voltage, and consequently any d.c. voltage value between about 400 volts and 500 volts can be considered satisfactory for this no-load d.c. output voltage measurement.

NOTE: Although the highest division on the *DC* scale is 4.5, corresponding to 450 volts when using the *100* × *V* range, voltages up to 500 volts d.c. can be safely measured. When the pointer is between the letters *D* and *C* at the right-hand end of the scale, read the meter as 5; multiplying by 100 then gives 500 volts. For pointer positions in between 4.5 and "5," estimate the reading just as you do between other divisions on the scale.

Discussion: The sole purpose of the pilot lamp in your a.c. power pack is to serve as an indicator that the power pack is on and is delivering a useful yet dangerously high voltage. Whenever this light is glowing, do not touch any terminal of the power pack or any voltage supply terminal of the equipment connected to the power pack. If you are making voltage measurements on any connected equipment with the N.R.I. Tester, be sure to hold the test clips by their insulated handles.

After turning off the power pack, wait at least five seconds for the condensers to discharge, before touching any terminals or parts with your fingers. The condensers may deliver an unpleasant shock while discharging, even though power is off.

INSTRUCTIONS FOR PERFORMING EACH EXPERIMENT

1. **Read the entire experiment, giving particular attention to the discussion.**
2. **Perform each step of the experiment and record your results. Whenever a measurement is specified, be sure to make it exactly according to the "OPERATING INSTRUCTIONS FOR N.R.I. TESTER" given in this manual for that type of measurement.**
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 31

***Purpose:* To measure the high d.c. output voltage, the low a.c. output voltage, and the a.c. ripple voltage which is present at the d.c. output terminals of the a.c. power pack under no-load conditions.**

Step 1. To measure the d.c. output voltage of your power pack, first place the power pack in an upright position before you on the table, with the terminal strip facing you, and connect the ground wire at your workbench to output terminal screw *3*.

Check the calibration of the N.R.I. Tester by following the instructions given elsewhere.

Prepare the N.R.I. Tester to read d.c. voltages according to the "D.C. VOLTAGE MEASUREMENTS" instructions given previously. Place the black test clip on output terminal *4* of the power pack, and place the red clip on output terminal screw *5*. (Terminals *4* and *5* are the d.c. output terminals, with terminal *4* negative and terminal *5* positive.)

Insert the power cord plug into a convenient a.c. outlet, turn on the power pack switch, allow about half a minute for the power pack to reach normal operating conditions, then turn on the N.R.I. Tester and read the meter on the *DC* scale. Record your result in Table *31* as the d.c. output voltage in volts for no load.

CAUTION: As was previously pointed out, high voltages exist at some terminals underneath the power pack chassis when this unit is in operation. Therefore, do not touch any terminals under the chassis with your fingers while the power pack switch is on.

Turning off the power pack switch breaks the primary circuit of the power transformer, but the 115-volt a.c. line voltage is still present at the power transformer primary terminals and at both power switch terminals. This means that it will be necessary to pull the power cord plug out of the outlet every time you make a change in the wiring under the chassis. Remember —do not touch the two power transformer primary terminals or the power switch terminals even when the power pack switch is off, unless you have first pulled out the plug.

Step 2. To measure the a.c. filament voltages provided by your a.c. power pack, first prepare the N.R.I. Tester for a.c. voltage measurements by following the "A.C. VOLTAGE MEASUREMENTS" instructions given elsewhere in this manual.

Place the test clips on output terminals *1* and *2*, measure the a.c. voltage, and record your result in Table *31* as the a.c. output voltage in volts across the entire filament winding (between terminals *1* and *2*).

CAUTION: Always return the selector switch to the highest range (*100* × *V*) when through making a voltage measurement, to prevent overloading of the meter on the next measurement. Before making a new measurement, be sure the probes are in the correct jacks for that type of measurement.

Next, place the clips on output terminals *1* and *3*, measure the a.c. voltage, and record your result in Table *31* as the a.c. output voltage across one half of the filament winding (between output terminals *1* and *3*).

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
1	D.C. OUTPUT VOLTAGE BETWEEN TERMINALS 4 AND 5	400	450
2	A.C. OUTPUT VOLTAGE BETWEEN TERMINALS 1 AND 2	4.52	6.7
	A.C. OUTPUT VOLTAGE BETWEEN TERMINALS 1 AND 3	2.5	3.5
	A.C. OUTPUT VOLTAGE BETWEEN TERMINALS 2 AND 3	2.5	3.4
3	A.C. RIPPLE VOLTAGE BETWEEN TERMINALS 4 AND 5	0	0

TABLE 31. Record your results here for Experiment 31. All power pack measurements in this table are for normal full-wave rectification and condenser input. No load is connected to the d.c. output terminals.

To measure the a.c. voltage across the other half of the filament winding, place the clips on output terminals *2* and *3*, read the meter on the *AC* scale, and record your result in Table *31* as the a.c. output voltage between terminals *2* and *3*.

Step 3. To measure the a.c. ripple voltage value which is present at d.c. output terminals 4 and 5, leave the tester set for a.c. voltage measurements. Review the "A.C. VOLTAGE MEASUREMENTS" instructions if in doubt. Place the black clip on output terminal screw *4*, place the red clip on output terminal screw *5* (polarity *is important* in this particular measurement, as pointed out in the discussion). Read the meter on the *AC* scale, and record your result in Table *31* as the a.c. ripple voltage in volts between output terminals *4* and *5*. If the pointer flickers back and forth continually, estimate its average position. If the pointer does not move at all from zero, record your result as zero volts.

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

A.C. VOLTAGE MEASUREMENTS

1. **Plug the black probe into the $-V_{AC}$ jack on the panel, and plug the red probe into the left-hand V_{AC} jack.**
2. **Set the selector switch at *100* × *V*.**
3. **Place the test clips on the terminals between which the a.c. voltage is to be measured. The black clip should go to the terminal which is closer to ground. When both terminals have essentially the same potential with respect to ground, the polarity of the test clip connections can be disregarded.**
4. **Turn on your apparatus, then turn on the N.R.I. Tester. This protects the tester against high-voltage surges which may exist when the apparatus is turned on.**
5. **Lower the selector switch setting, one range at a time, until you reach the lowest range which does not make the meter pointer swing off-scale.**

IMPORTANT: When working with apparatus using vacuum tubes, wait long enough for the tubes to warm up (about half a minute is sufficient) before lowering the selector switch setting. This applies whenever you use the entire a.c. power pack (with the rectifier tube in its socket).

6. **Read the meter on the *AC* scale, and multiply the reading by the correct factor for the range being used.**
7. **Turn off the N.R.I. Tester first, then turn off the power source. Pull out the test probes when through using the N.R.I. Tester, to prevent draining of the C battery in case the test clips accidentally touch the tester panel or chassis.**

NOTE: When the N.R.I. Tester is being used as an a.c. voltmeter on the *V* range, a meter reading may be obtained *when only one test clip is connected*. This is due to pick-up of stray a.c. energy by the test leads. Disregard this condition, as it has no effect on the readings when both test leads are connected.

Discussion: In Step 1, you repeat your measurement of the d.c. output voltage so that you can record this value in Table *31* along with the other output voltage values of your a.c. power pack. You will use the values which you record in this table for reference purposes in connection with later experiments.

Although a.c. line voltages in this country are ordinarily somewhere around 115 volts, these voltages will vary anywhere between 110 volts and 120 volts at times, due to changes in the loads on a power system and to other conditions at the power generating station. Each variation in the a.c. line voltage will cause a corresponding variation in the d.c. output voltage of your power pack. Thus, you may get a different value if you measure this d.c. output voltage tomorrow or next week.

In boosting the a.c. line voltage, your power pack inherently amplifies the variations in the line voltage. If you are located in an industrial community where there are large varying electrical loads on the power system, you may even be able to see this variation, in the form of a continual flickering of the meter pointer when measuring the d.c. output voltage of the power pack.

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

EXTENDING VOLTAGE RANGES

As your N.R.I. Tester has a resistance of 10 megohms, you can double the values for any a.c. or d.c. voltage range of the N.R.I. Tester by inserting in series with the tester and the voltage source the 10-megohm resistor which is supplied to you as Part *4-21*.

Simply connect this resistor temporarily in series with the ungrounded test lead. The true voltage reading will then be the meter reading multiplied by *twice* the multiplying factor indicated at the selector switch setting. Thus, when using this voltage multiplier on the *100 × V* range, a meter reading of 2.4 would correspond to 480 volts.

When dealing with voltages between about 20 and 30 volts, the use of the voltage multiplier with the *3 × V* range will give a more accurate measurement than could be obtained with the *30 × V* range. This is particularly true in the case of a.c. measurements.

In Step 2, you use the N.R.I. Tester as a low-range a.c. voltmeter and measure the a.c. output voltages which are provided at the output terminals of your power pack for filament heating purposes. In connecting between output terminals *1* and *2* for the first measurement, you measure the voltage across the entire filament winding (between terminals *19* and *21* in Fig. *2*). Although this voltage should normally be about 6 volts a.c., for use with 6 or 6.3-volt vacuum tube filaments, you will measure a somewhat higher voltage under no-load conditions. This is entirely normal, for the voltage will drop when vacuum tube filaments are connected to these terminals.

The circuit diagram in Fig. *2* shows that the 6.3-volt filament winding has a center tap, going to output terminal *3*. For the second and third measurements, you measure between this center tap and each of the outer terminals of the 6.3-volt filament winding. If you secure essentially equal voltage values for these two measurements, you know that the center tap has been placed in the electrical center of the filament winding, as it should be. The sum of the voltages across the two halves of the filament winding is equal to the voltage across the entire winding, but voltage values measured with the N.R.I. Tester may differ as much as 10% when checked in this manner.

In Step 3, you set the N.R.I. Tester for use as an a.c. voltmeter and con-

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

IF N.R.I. TESTER READINGS SEEM WRONG, CHECK THESE ITEMS

1. Are the test clip, test probe and selector switch positions correct for the type of measurement you are making?
2. Are you reading the correct scale on the meter?
3. Are you multiplying the scale reading by the correct factor for the selector switch setting?
4. Is the calibrating clip placed on the correct permanent C battery terminal (—9C)? If through forgetfulness you leave the clip on the less negative terminal, all meter readings will be too high.
5. Did you follow *every step* of the instructions given in the manual for making the measurement in question?

NOTICE: WHEN WRITING TO THE INSTITUTE REGARDING YOUR N.R.I. TESTER, BE SURE TO REFER TO IT AS THE "N.R.I. TESTER FOR EXPERIMENTS."

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

REDUCING LEAKAGE RESISTANCE EFFECTS

Leakage resistance in the grid circuit of the N.R.I. Tester can provide a path for direct current through the meter circuit when measuring the a.c. ripple voltage at the high-voltage d.c. output terminals, thereby giving a meter reading even when the a.c. ripple voltage is zero. The condenser which was supplied you for use between the $+V_{DC}$ jack and the left-hand V_{AC} jack behind the panel of the tester has an unusually high leakage resistance value, but moisture or dust on the condenser housing or on either side of the insulating strip which supports the jacks may provide sufficient leakage resistance to give a meter reading. Likewise, moisture or dirt on the tube base or tube socket of the N.R.I. Tester can cause grid-to-filament leakage and give the same effect. This leakage is particularly troublesome under conditions of extremely high humidity, such as in a damp basement.

To reduce the effects of leakage resistance to a minimum, turn off all apparatus, then remove the mounting screws for the jack strip on the N.R.I. Tester so you can wipe both sides of this strip with a clean cloth. Replace the jack strip, then wipe the housing of the .005-mfd. condenser carefully with the cloth, wipe the tube base between the prongs, and wipe the surface of the tube socket both above and below the chassis.

nect it to the d.c. output terminals of the power pack. When using the *AC* voltmeter range of the N.R.I. Tester in this manner, a .005-mfd. condenser in series with the measuring circuit inside the tester blocks the flow of direct current. Under this condition, the only voltage which can affect the meter reading under normal conditions is the a.c. ripple voltage which might be present at the d.c. output terminals.

Small variations in the line voltage can cause considerable flickering of the meter pointer while you are measuring the a.c. ripple voltage in the d.c. output. The power transformer increases the line voltage variations about four times, and the sudden charging and discharging of condensers in the filter system can amplify the variations still further, so that they are quite noticeable when measured with the lowest *AC* range of the N.R.I. Tester. Reading the average value over which the pointer flickers will eliminate these variations from your results.

Blistering of Paint on Resistors. The 50,000-ohm resistor under the power pack chassis develops considerable heat during normal operation of the power pack, for it is connected directly across a pulsating d.c. voltage of over 400 volts at the rectifier tube output. This heat may cause the paint on the resistor to become soft and develop blisters, but this will in no way affect the quality of the resistor or the operation of the power pack. This same blistering of paint may occur in the 40,000-ohm resistors which you use across the d.c. output terminals in the next experiment.

Bleeder Resistor. The 50,000-ohm resistor is connected across the input of the power pack filter system at all times, and serves to prevent high-voltage surges from damaging the electrolytic filter condenser when the power pack is first turned on and there is no load connected to the d.c. output terminals. This resistor is actually an internal load on the power pack, and is called a *bleeder resistor* because it draws or "bleeds" a current continuously for stabilizing purposes, regardless of what is connected externally to the power pack.

When reference is made to the power pack load, we always mean the load which is connected externally to the output terminals. You can neglect the presence of the internal bleeder resistor load during normal use of the power pack.

Instructions for Report Statement No. 31. In the preceding discussion, it was pointed out that the d.c. output voltage of your power pack will vary with the a.c. line voltage. To familiarize you with the proper and safe technique for measuring this line voltage, you are asked to make this measurement and record it in Report Statement No. 31, along with your measured value for the d.c. output voltage.

With the power pack plug pulled out, turn the power pack chassis on its back side, place one test clip on power switch terminal *10*, and place the other test clip on transformer terminal *25*, so that you will be measuring the voltage between the two leads of the power cord. Adjust the clips carefully so that they cannot loosen and touch other parts. Now prepare the tester for a.c. voltage measurements, as instructed elsewhere. Insert the power cord plug in the wall outlet, and turn on the N.R.I. Tester. Record your a.c. line voltage in volts in Report Statement No. 31. Pull out the power cord plug before touching the test clips.

Now repeat your measurement of the d.c. output voltage of the power pack, exactly as instructed in Step 1 of this experiment. Record this value also in Report Statement No. 31, as the d.c. output voltage corresponding to the line voltage value you measured. This output voltage may be different from that which you recorded in Table *31*, but you know now that this is due simply to line voltage variations.

EXPERIMENT 32

***Purpose:* To show that the d.c. output voltage of your a.c. power pack varies with the load.**

Step 1. To connect four 40,000-ohm resistors in parallel to the d.c. output terminals of the power pack so as to secure a 10,000-ohm load, first secure the four 40,000-ohm, 3-watt resistors (Parts *3-6A*, *3-6B*, *3-6C* and *3-6D*) which were supplied you in Radio Kit 3RK. Bend a hook in each lead of one resistor in the manner shown in Fig. *11A,* loosen the screws on output terminals *4* and *5* of the power pack, hook these resistor leads over screws *4* and *5*, then tighten the screws while holding the resistor with your fingers and exerting a gentle upward pull to keep the hooks under the screw heads. Now bend the resistor leads downward until the resistor is about on a level with the screws.

Take another 40,000-ohm resistor, tin the ends of its leads, and connect this resistor in parallel with the first one by means of temporary soldered joints after bending and arranging the leads as shown in Fig. *11B*.

Connect the remaining two 40,000-ohm resistors in parallel with the first two resistors by means of temporary soldered lap joints in the same manner, so that you now have a parallel combination of four resistors like that shown in Fig. *11C*. These give the desired equivalent resistance of 10,000 ohms.

Step 2. To measure the d.c. output voltage of your power pack with various load values, first check the calibration of the N.R.I. Tester, then prepare it for d.c. voltage measurements according to previous instructions. Place the red clip on the resistor lead which is attached to terminal *5*, bringing the clip up from under the lead as shown in Fig. *11C* to minimize chances of the clip touching the chassis. In the same manner, place the black clip on the lead which is attached to terminal *4*. Record your result in Table *32* as the d.c. output voltage when using a 10,000-ohm load.

To measure the d.c. output voltage for a 20,000-ohm load, remove two of the resistors from your parallel group by unsoldering one resistor lead in the manner shown in Fig. *11D*. The two 40,000-ohm resistors which are still connected to output terminals *4* and *5* give a load resistance of 20,000 ohms. Leave the clips connected as before, follow the "D. C. VOLTAGE MEASUREMENTS" instructions, and record the result in Table *32* as the d.c. output voltage in volts for a 20,000-ohm load.

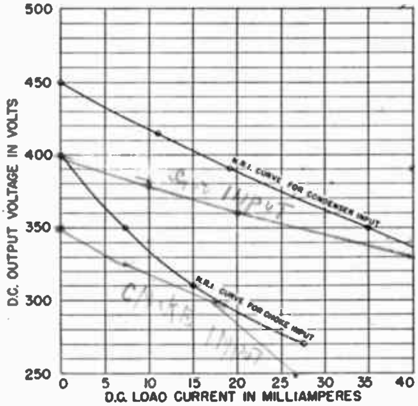
LOAD RESISTANCE IN OHMS	D.C. OUTPUT VOLTAGE IN VOLTS		D.C. LOAD CURRENT IN MILLIAMPERES	
	YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.
10,000	340	350	34	36
20,000	360	390	16	20
40,000	380	420	10	11
NO LOAD	400	450	0	0

TABLE 32. Record your results here for Experiment 32. All power pack measurements in this table are for normal full-wave rectification and condenser input. Load values are as indicated in the first column above. Always use pencil rather than ink for recording your values in the tables. Be sure you record each value in the correct position in the table.

To measure the d.c. output voltage for a 40,000-ohm load, unsolder one more resistor lead in the manner shown in Fig. *11E*, so that only one 40,000-ohm resistor is connected to terminals *4* and *5*. Record your result in Table *32* as the d.c. output voltage for a 40,000-ohm load.

To measure the d.c. output voltage for no load, remove the test clips, remove the entire resistor group from output terminals *4* and *5*, place the red clip on the screw of terminal *5*, place the black clip on the screw of terminal *4*, measure the d.c. output voltage exactly as you did in Experiment 31, and record your result in Table *32* as the no-load d.c. output voltage in volts. Pull out the power cord plug, remove the test leads entirely, and turn off the tester.

Step 3. To measure load currents for the three load resistance values used in Step 2, first connect the four 40,000-ohm resistors in parallel again by means of temporary soldered lap joints to secure a 10,000-ohm resistance. Connect one lead of this resistor group to output terminal screw *5*. Place the red test clip on the other lead of the resistor group, and place the black test clip on output terminal screw *4*, as shown in Fig. *11F*.



GRAPH 32. Plot your results for Experiment 32 on this graph and draw a smooth line through the dots to secure a d.c. load current-d.c. output voltage curve which you can compare with the N.R.I. curve for condenser input. Later, you will use values obtained in Experiment 36 to plot another curve on this graph for a choke input type of filter circuit.

Prepare the tester for direct current measurements by placing the black test probe in the *—I* jack, placing the red test probe in the *+I* jack, and setting the selector switch at *10 × I*. (This covers items 1 and 2 in the "DIRECT CURRENT MEASUREMENTS" box on page 25. The previous paragraph covered items 3 and 4, and the following paragraph here covers the remaining items—5, 6 and 7.)

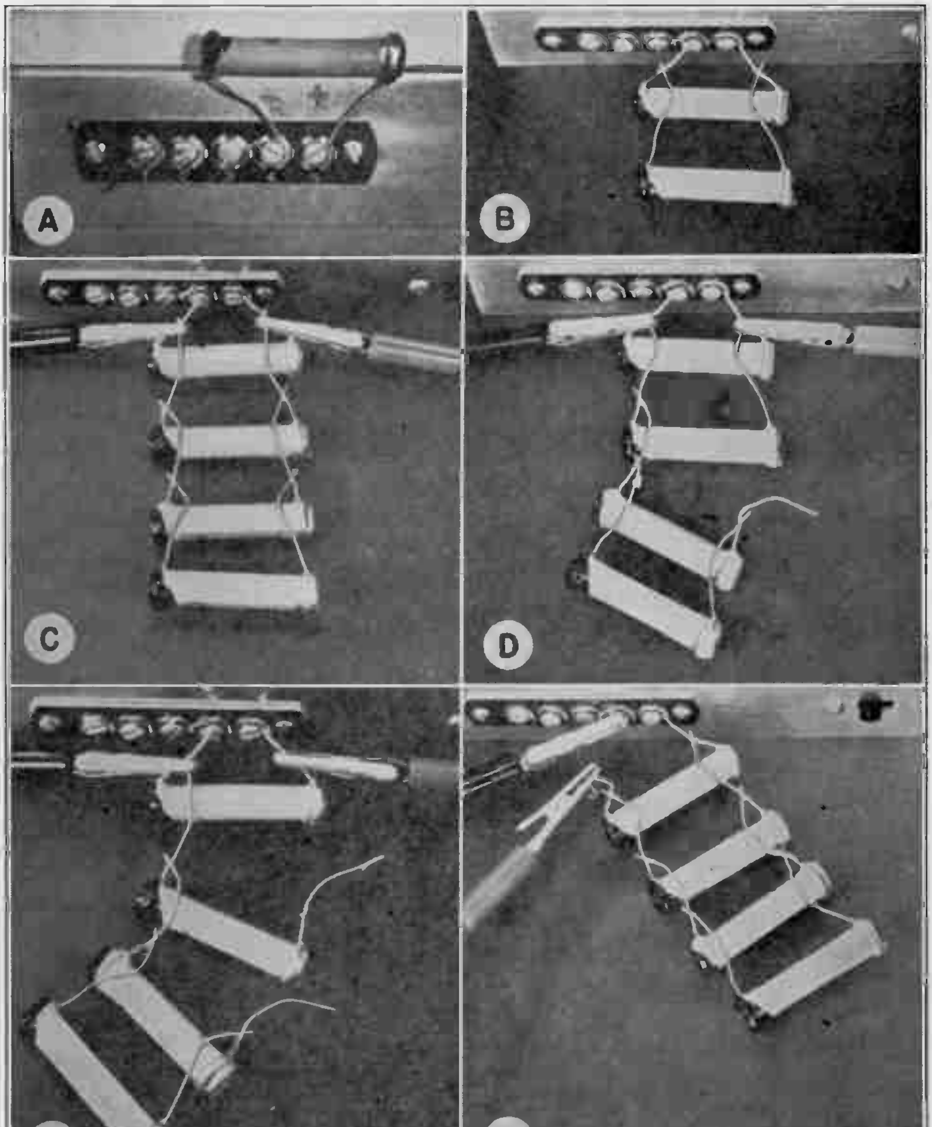


FIG. 11. Methods of connecting load resistors to the d.c. output terminals of your power pack for d.c. output voltage and d.c. load current measurements are illustrated here.

A—Method of connecting a single 40,000-ohm load resistor to d.c. output terminals *4* and *5*.

B—Two 40,000-ohm resistors connected in parallel to output terminals *4* and *5* as shown here will serve as a 20,000-ohm load.

C—Four 40,000-ohm resistors in parallel give a 10,000-ohm load. If the red and black test clips are attached in the manner shown here when making d.c. output voltage measurements, there is little possibility of the clips accidentally shorting together or touching the chassis.

D—Method of disconnecting two resistors temporarily to give a 20,000-ohm load.

E—Method of disconnecting three resistors temporarily to give a 40,000-ohm load.

F—Method of connecting the test clips for measurement of the d.c. load current through a 10,000-ohm load resistance. Note that current is measured at the grounded point (terminal *4*) in the load circuit; this keeps the chassis of the N.R.I. Tester at ground potential.

To measure the direct current flowing through the 10,000-ohm load, turn on the power pack and the tester, wait half a minute, read the meter on the *DC* scale, multiply the meter reading by 10, and record your result in Table *32* as the d.c. load current in ma. for a 10,000-ohm load.

While leaving the test probes exactly as shown in Fig. *11F*, turn off the power pack, and remove *completely* two of the resistors from the parallel group so as to secure a 20,000-ohm load. Now measure the current through this 20,000-ohm load in the same manner (you can follow the general instructions in the box on page 25 if you prefer, but *don't move the test clips)*, and record your result in Table *32* as the load current in ma. for a 20,000-ohm load.

With the test probes still exactly in the positions shown in Fig. *11F*, turn off the power pack again, and remove completely one of the remaining two 40,000-ohm resistors, so that you now have only one 40,000-ohm resistor left to serve as load. Measure the current through this 40,000-ohm load in the same manner as before, and record your result in Table *32* as the load current in ma. for a 40,000-ohm load.

When the last 40,000-ohm resistor is removed from terminal *5*, there is no load, and hence no load current can flow. *Do not make any measurement at all* for the no-load current box in Table *32;* just record a zero in this box.

Step 4. To plot a graph which will show how d.c. output voltage varies with load current, first plot on Graph *32* the d.c. output voltage you measured for no-load conditions, by placing a heavy dot at this voltage value on the vertical scale at the left of the graph. Next, locate on the horizontal scale the current value for the 10,000-ohm load, and draw a light *vertical* line through this value on the graph. Locate on the vertical scale the d.c. output voltage measured for this load value, draw a light *horizontal* line through this value, and make a heavy dot at the point where it intersects your vertical line.

In the same manner, plot in turn similar points for the 20,000 and 40,000-ohm loads. Now connect your four points together with a smooth line to give a curve of load current plotted against d.c. output voltage.

Discussion: Step 1 is a preliminary step which gives you additional experience in making the temporary soldered lap joints which are used so extensively by radio servicemen for test connections. You may have some difficulty in making these joints unless you first tin the leads individually; in fact, the professional technique for making lap joints always involves preliminary tinning of the individual parts. This eliminates the necessity for having to apply solder while actually soldering the joints, so you can hold in one hand the part being soldered, and hold the soldering iron in the other hand.

After making the six soldered lap joints called for in Step 1, check your work by wiggling the wires of each joint. Sometimes a joint which appears secure is held together only by rosin, which is an insulator; this wiggling procedure will reveal defective rosin joints by breaking the rosin bond.

When resistors of equal value are connected in parallel, the combined resistance is always equal to the value of one of the resistors divided by the number of resistors in parallel. This is a valuable rule to remember.

Although the 40,000-ohm resistors which you use in this experiment have a power-handling rating of 3 watts, it is entirely permissible to overload

OPERATING INSTRUCTIONS FOR N.R.I. TESTER

DIRECT CURRENT MEASUREMENTS

1. **Place the black test probe in the *—I* jack, and place the red test probe in the *+I* jack.**
2. **Set the selector switch at *10×I*.**
3. **Open the circuit at the point where current is to be measured. Although current can be measured anywhere in a circuit, it is best to make this measurement at a point which is at *ground* potential or as close as possible to ground potential. (Output terminal *4* of your power pack is at ground potential because the ground wire connects both to *3* and *4*.) Observance of this rule minimizes chances of getting a shock when touching the tester chassis with one hand and touching a grounded object like the power pack chassis with the other hand.**
4. **Place the black test clip on the grounded terminal (or lead) at the measuring point, and place the red test clip on the lead which you disconnected from this grounded terminal. This places your N.R.I. Tester *in series* with the circuit, just as it should be for all current measurements.**
5. **Turn on the voltage source and the N.R.I. Tester, wait about half a minute if there are any heater-type tubes in your set-up, then read the meter on the *DC* scale and multiply the reading by 10 to get the current in milliamperes.**
6. **If the current value is less than 4.5 ma., set the selector switch at the *I* range and read the direct current value in ma. directly on the *DC* scale.**
7. **Turn off the N.R.I. Tester, then turn off the power source. Pull out the test probes to prevent draining the C battery in case the test leads accidentally touch the tester panel or chassis.**

IMPORTANT: For all direct current measurements, be sure to read the meter on the *DC* scale (not on scale I_M).

these resistors for short periods of time. The resulting heat may change the appearance (color) of a resistor and produce smoke, but this will not affect the electrical characteristics.

When working on this experiment, keep in mind that the load is increased by lowering (decreasing) the ohmic value of the load resistance. In other words, you have the greatest load on your power pack when all four resistors are connected in parallel to give a combined resistance of 10,000 ohms. You should therefore expect to secure the lowest d.c. output voltage when this load is employed. Increasing the value of the load resistance to 20,000 and then to 40,000 ohms reduces the loading effects, and consequently the measured d.c. output voltage should go up. Examine your results in Table *32* to verify this.

When you analyze your measured values of load current, you should find that the d.c. load voltage is the lowest and the load current is the highest for the 10,000-ohm load. When you plot the load current values on Graph *32* and draw the curve through the points, your resulting curve can be compared to the N.R.I. curve for condenser input in Graph *32*. You will see that the d.c. output voltage increases gradually to the no-load value as the load current is reduced by increasing the load resistance. Furthermore, with your curve you can determine what the d.c. output voltage will be for any intermediate value of load current.

Warning: Smoke coming from the N.R.I. Tester during direct current measurements means you have not made the correct series connection for a current measurement. Turn off the power pack at once, and move the test probes to the correct positions, as instructed in the box on page 25.

Load Current Computations. You can easily check your measured values of load current by means of Ohm's Law. To compute what the load current in amperes will be, divide the measured value of d.c. output voltage by the ohmic value of the load resistance employed. Multiplying the result by 1,000 will give you the load current in milliamperes. You can do this for one or two of the load values in Table *32* if you wish, to see how well your computed and measured values agree. Of course, you cannot expect perfect agreement because the actual ohmic values of the resistors may be as much as 20% off from rated values due to normal manufacturing tolerances.

Your a.c. power pack was designed to deliver at least 350 volts d.c. at a d.c. load current value of 25 ma., when connected to a standard 115-volt, 60-cycle power line. The curve of results obtained in the N.R.I. laboratory shows that the d.c. output voltage is well above 350 volts at this rated full-load current of 25 ma.

Your power pack is capable of delivering considerably more than the rated output current for *short* periods of time, as you actually demonstrated.

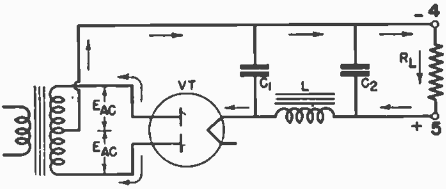


FIG. 12. Simplified schematic circuit diagram of the high-voltage section of your a.c. power pack, with arrows indicating the direction of electron flow. R_L represents an external load resistance connected to d.c. output terminals *4* and *5* of the power pack.

Review of Rectifier Action. Although the operating principles of rectifier circuits are fully covered in your regular course, now is an excellent time to review these important principles briefly, and see just why the d.c. output voltage drops as load is applied.

To explain the theoretical operation of your a.c. power pack, the simplified schematic circuit diagram in Fig. *12* will be easier to follow than the detailed schematic diagram in Fig. *2*. Rectifier tube *VT* in Fig. *12* allows each power transformer secondary voltage E_{AC} in turn to send electrons through load resistor R_L and choke coil *L* in one direction only, as indicated by arrows.

Input filter condenser C_1 (Fig. *12*) is charged by the pulsating d.c. voltage produced by the rectifier tube-transformer combination. When the pulsating d.c. source voltage drops below the condenser voltage, this condenser discharges through R_L and *L;* the condenser current then adds to the existing current flow over this path, thereby keeping the load current nearly constant despite the fact that the pulsating d.c. voltage is dropping to zero between each half cycle.

If the resistance values of *L* and R_L are reasonably high, the voltage across C_1 will more or less follow the peaks of the rectified voltage during this action.

Increasing the power pack load by reducing the resistance value of R_L affects the power pack circuit in three different ways, with each of these tending to make the d.c. output voltage drop.

First of all, an increased load makes C_1 discharge more completely in between the peaks of the pulsating d.c. voltage, with the result that the average d.c. voltage value across input filter condenser C_1 is reduced. This is one reason why the d.c. output voltage goes down as more load is applied.

Secondly, whenever direct current is drawn from the power pack, this current must flow through the d.c. resistance of the power transformer secondary winding, through the d.c. resistance of rectifier tube *VT*, and through the d.c. resistance of choke coil *L*. Increasing the load current increases the voltage drops across these three d.c. resistances, thereby reducing the amount of d.c. voltage available at output terminals *4* and *5*.

Finally, the a.c. voltage supplied by the power transformer secondary winding will drop when more current is drawn from this winding. The power transformer must supply more energy when the load is increased, and consequently the alternating currents flowing through both the primary winding and the high-voltage winding must increase when the load current increases. Each transformer winding has an a.c. resistance due to eddy current and hysteresis losses as well as normal copper losses; the increased flow of alternating current through these a.c. resistances lowers the a.c. voltage available at the terminals of the high-voltage secondary winding for rectification purposes.

Instructions for Report Statement No. 32. By referring to the curve which you plotted in Graph *32*, determine what the d.c. output voltage of your power pack will be for a d.c. load current of 25 ma. when using the condenser-input filter circuit shown in Figs. *2*, *8*, and *12*. This is done by tracing upward from 25 ma. on the horizontal scale until you intersect your curve, then tracing horizontally leftward to the vertical axis and reading the d.c. voltage value there. Record this voltage value in the space provided for this purpose in Report Statement No. 32 on the last page.

EXPERIMENT 33

Purpose: **To demonstrate the voltage regulation characteristics of both the low and high-voltage secondary windings of the power transformer in your power pack.**

Step 1. To measure the full-load and no-load voltages of the low-voltage secondary winding in your power pack, first take the length of resistance wire which is supplied as Part *4-11* and connect it between output terminals *1* and *2* on the power pack by bending an open hook in each end of the wire, slipping one hook under the screw of output terminal *1* and tightening this screw, then slipping the other hook under the screw of output terminal *2* and tightening this screw. Bend the loop of resistance wire so that it does not touch the chassis or other nearby objects. This length of wire has a resistance of 3 ohms, which is the correct value for drawing full-load current from the 6.3-volt filament winding of the power pack.

Prepare the tester for a.c. voltage measurements and place the test clips on output terminals *1* and *2* underneath the chassis. (Under-chassis connections are used because it is difficult to make the clips grip the terminal screws while they are tightened over the resistance wire.) The chassis should be resting on its back side so that these terminals will be readily accessible. Measure the a.c. voltage between terminals *1* and *2*, and record your result in Table *33* as the voltage in volts at a.c. output terminals *1* and *2* for full load of 3 ohms.

Remove the length of resistance wire from terminals *1* and *2*, measure the a.c. voltage between output terminals *1* and *2*, and record your result in Table *33* as the no-load a.c. output voltage value in volts of the 6.3-volt filament winding (between terminals *1* and *2*).

CAUTION: Do not touch the resistance wire with your fingers while the power is on, and allow ample time (about one minute) for the wire to cool after power is turned off. This wire becomes almost red hot, and can cause an unpleasant burn if touched. Use long-nose pliers if for any reason you have to handle the wire while still hot.

STEP	NATURE OF MEASUREMENT	A.C. VOLTAGE IN VOLTS	
		YOUR VALUE	N.R.I. VALUE
1	VOLTAGE AT A.C. OUTPUT TERMINALS 1 AND 2 FOR 3Ω LOAD	6.0	6.0
	VOLTAGE AT A.C. OUTPUT TERMINALS 1 AND 2 FOR NO LOAD	6.7	6.7
2	VOLTAGE AT TRANSFORMER TERMINALS 22 AND 23 FOR 10,000Ω LOAD	310	350
	VOLTAGE AT TRANSFORMER TERMINALS 22 AND 23 FOR NO LOAD	325	375

TABLE 33. Record your results here for Experiment 33. All power pack measurements in this table are for normal full-wave rectification and condenser input.

Step 2. To measure full-load and no-load a.c. voltages across one half of the high-voltage secondary winding, first connect a 10,000-ohm load to d.c. output terminals *4* and *5* by connecting the group of four 40,000-ohm resistors in parallel again with temporary soldered lap joints, then connecting the group between output terminals *4* and *5*. Be sure the resistor leads do not touch the chassis.

With the chassis resting on its back side to make the power transformer terminals accessible, measure the a.c. voltage between transformer terminals *22* and *23* and record your result in Table *33* as the a.c. voltage in volts across one half of the high-voltage secondary winding (between terminals *22* and *23*) for a 10,000-ohm load.

Remove the 10,000-ohm load from the power pack by disconnecting the group of four resistors from terminals *4* and *5*, measure the a.c. voltage again between terminals *22* and *23*, and record your result in Table *33* as the no-load a.c. voltage in volts across one half of the high-voltage secondary winding (between terminals *22* and *23*).

Discussion: In Step 1, you placed directly across the separate 6.3-volt filament winding in your power pack a resistance which draws from this winding its rated output current of about 2 amperes. When you measure the a.c. output voltage while this load is present, you find the voltage to be appreciably lower than for the corresponding no-load condition.

In Step 2, you again observe this same drop in voltage with load when you place a 10,000-ohm load across the output terminals of the power pack so as to increase the effective load on the high-voltage secondary winding of the power transformer. You have thus proved that the a.c. voltage at the high-voltage secondary winding drops when load is applied to the power pack, exactly as was pointed out in Experiment 32 (in the review of rectifier action), and have demonstrated for yourself one of the three reasons why the d.c. output voltage drops with load.

Transformer Theory. To understand why the secondary voltage of a power transformer drops as load is applied, we must review the basic action of an iron-core transformer.

Although a power transformer is one of the most efficient devices employed in the electrical and radio industries, it is by no means entirely perfect. A power transformer has copper losses, hysteresis losses and eddy current losses, and these along with the reactances of the windings serve to reduce the output voltage when the transformer is loaded.

Consideration of the equivalent transformer circuit shown in Fig. *13* will help you to understand the actions occurring in a practical transformer.

If a definite load voltage value V_L is required across load R_L in Fig. *13*, the secondary winding of the ideal transformer must supply a higher voltage E_s which will be equal to the vectorial sum of the load voltage V_L, the a.c. voltage drop across the secondary a.c. resistance value R_s, and the a.c. voltage drop across the secondary inductive reactance X_s. The higher the load current, the higher are the voltage drops across R_s and X_s, and the higher must E_s be to overcome these drops.

A definite transformer primary voltage E_P is required to provide secondary voltage E_s, assuming perfect coupling in this ideal transformer. The supply voltage E must be higher than this primary voltage, however, for it has to overcome the a.c. voltage drop across the primary a.c. resistance R_P and the a.c. voltage drop across the primary inductive reactance X_P.

We thus see that the voltage drops across the primary and secondary resistances and reactances in a power transformer make necessary a *higher* input voltage than would be required in a perfect transformer to secure a desired output voltage. This means that when the input voltage is fixed (as it is for the average power line connection), these voltage drops make the output voltage *lower* than that for a perfect transformer. Increasing the load makes these voltage drops increase, thereby reducing the output voltage still more if the input voltage remains constant.

Further study of the results you obtained in this experiment will show that at no load, the d.c. output voltage of the power pack is higher than the a.c. voltage across each half of the high-voltage secondary winding. Thus, the N.R.I. values show an a.c. secondary voltage of 375 volts and a no-load d.c. output voltage of 450 volts.

This does not mean, however, that we are getting voltage step-up in the filter circuit. The measured a.c. voltage value of 375 volts in the N.R.I. case is an *effective* or *r.m.s. value,* and the instantaneous voltage will actually swing up to 1.4 times this effective value on peaks. This means that the peak a.c. voltage value present across one half of the secondary winding is 1.4 × 375 volts, or 525 volts. This value of 525 volts represents the theoretical absolute limit of the no-load d.c. output voltage. By bridging the valleys between peaks, the filter condensers tend to make the d.c. output voltage approach this peak value during no-load conditions.

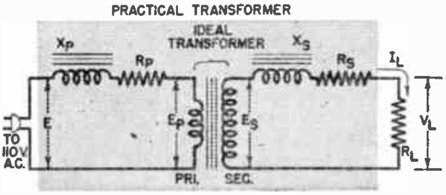


FIG. 13. Simplified equivalent circuit diagram for the primary winding and high-voltage secondary winding of a power transformer. The portion of the diagram designated as an ideal transformer has no losses. Parts X_P, R_P, R_S and X_S represent equivalent loss-producing resistances and reactances which are present in a practical iron-core transformer.

As load is applied to the power pack, the d.c. output voltage value drops, and may even go below the effective a.c. secondary voltage value, for increased load makes the input filter condenser discharge more completely during each rectified half cycle.

Instructions for Report Statement No. 33. In this experiment, you determine for yourself the effect which a load connected to the d.c. output terminals of your power pack has upon the a.c. voltage existing across one half of the high-voltage secondary winding of the power transformer. Report Statement No. 33 gives you a chance to express your own conclusion regarding this particular experiment, and at the same time tells us whether you have performed the experiment properly and mastered the important principle it is intended to demonstrate.

Turn to the last page, and place a check mark after the answer in Report Statement No. 33 which expresses the change you observed in the a.c. voltage across one half of the high-voltage secondary winding of the power transformer (between terminals *22* and *23*) when you applied a 10,000-ohm load to the d.c. output terminals of the power pack.

EXPERIMENT 34

***Purpose:* To show that most of the ripple voltage which is present across the input filter condenser of the power pack is dropped in the choke coil, and to show that the a.c. ripple voltage across the input filter condenser increases with load.**

Step 1. To measure ripple voltages in your a.c. power pack when a 40,000-ohm load is connected to the d.c. output terminals, first rest the chassis on its back side so that both the under-chassis connections and the output terminal screws are conveniently accessible. Take the group of four parallel-connected resistors used in the previous experiment, unsolder from the first resistor (the one having hooks in its lead) the other three resistors, then connect this single resistor to output terminals *4* and *5*.

Locate the 50,000-ohm bleeder resistor under the chassis (this is connected across the input of the power pack filter system, as shown in Fig. *2*). Measure the a.c. voltage across this resistor, being sure to place the black clip on the grounded resistor lead (place the black clip on the resistor

STEP	LOAD VALUE IN OHMS	A.C. VOLTAGE IN VOLTS ACROSS INPUT CONDENSER		A.C. VOLTAGE IN VOLTS ACROSS CHOKE COIL		A.C. VOLTAGE IN VOLTS AT D.C. OUTPUT TERMINALS	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
1	40,000	3.8	3.5	2.7	3.5	2.5	0
2	10,000	6.75	6.3	5.	6.3	2.1	0

TABLE 34. Record your results here for Experiment 34. All power pack measurements in this table are for normal full-wave rectification and condenser input.

lead going to condenser terminal *27*, and place the red clip on the resistor lead going to socket terminal *8*). Record your result in Table *34* as the a.c. voltage in volts across the input filter condenser for a 40,000-ohm load. (The bleeder resistor is in parallel with the input filter condenser.) Wait a few seconds for the condensers to discharge before touching any terminals, after turning off the power pack.

To measure the a.c. ripple voltage across the choke coil, place one clip on choke coil terminal *14*, place the other clip on choke coil terminal *13*, read the meter on the *AC* scale, and record the result in Table *34* as the a.c. voltage in volts across the choke coil for a 40,000-ohm power pack load. Polarity of the test leads is unimportant in this case. However, this measurement is made in the hot side of the circuit. This places the tester chassis at a high potential with respect to ground, so do not touch the tester chassis and the power pack chassis at the same time while power is on.

To measure the a.c. ripple voltage at the d.c. output terminals of the power pack, place the red clip on output terminal screw *5* or on the resistor lead attached to this terminal, place the black clip on output terminal screw *4*, and record your result (even if it is *0*) in Table *34* as the a.c. ripple voltage at the d.c. output terminals for a 40,000-ohm power pack load.

Step 2. To measure a.c. ripple voltage values in your power pack when a 10,000-ohm load is connected to the d.c. output terminals, first solder your parallel-connected group of three 40,000-ohm resistors (left over from the previous experiment) in parallel with the 40,000-ohm resistor which is already connected to output terminals *4* and *5*, using temporary soldered lap joints just as you did in the previous experiment. Now, repeat each of the measurements called for in Step 1. Record your values in Table *34* as the a.c. ripple voltages for a 10,000-ohm power pack load.

Allow the 40,000-ohm resistors a few minutes to cool before touching them with your fingers; they become quite hot while serving as power pack loads.

When you have completed all measurements for this step, remove the 40,000-ohm resistors from output terminals *4* and *5*, but leave the resistors connected in parallel for the present.

Discussion: This experiment shows you that even though appreciable a.c. ripple may exist at the input of the filter system in the power pack (across the input filter condenser), the filter system reduces this a.c. ripple so much that the amount of ripple present at the d.c. output terminals is negligible and is so small that it cannot ordinarily be measured with the N.R.I. Tester. You also see for yourself how an increase in load makes the input a.c. voltage across the input filter condenser go up, with the choke coil still absorbing practically all of this voltage, so that the a.c. ripple at the d.c. output terminals is still too small to be measured.

In the regular lessons of your N.R.I. course, you learned that the input condenser of a filter circuit accepts electrons and charges up whenever the voltage delivered by the rectifier tube is higher than the existing voltage across this condenser. When the rectifier tube voltage is lower than that of the input filter condenser, the condenser cannot discharge in the reverse direction through the rectifier tube, and hence it discharges through the series circuit consisting of the choke coil and the power pack load. The rate at which this input filter condenser discharges is determined by the capacity value of the condenser and the total resistance value through which it discharges (the choke coil resistance + the load resistance).

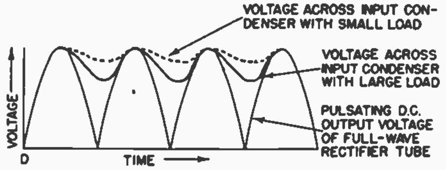


FIG. 14. Wave forms of voltages existing at different points in a power pack employing full-wave rectification and a condenser input filter.

The lower the ohmic value of the load, the lower is the total resistance through which the input filter condenser discharges; a low load resistance (corresponding to a large load) thus makes the input filter condenser discharge more completely in between peaks, as indicated by the solid-line curve in Fig. *14*. You can readily see that there is more a.c. ripple in this curve than there is in the dotted-line curve corresponding to a small load (high load resistance value). This explains why you obtained higher a.c. ripple voltage values for the 10,000-ohm load than you did for the 40,000-ohm load.

Since the choke coil and the output filter condenser are in series across the input filter condenser, these two parts really form an a.c. voltage divider connected across the input filter condenser. Therefore, according to Kirchhoff's Voltage Law, the voltage drop across each of the two parts will be proportional to the impedance of that part.

One requirement in the design of a filter circuit is a high choke coil impedance with respect to the output condenser impedance at the ripple frequency. When this condition is secured, most of the a.c. ripple voltage is dropped across the choke coil, and very little will be present across the output filter condenser and across the power pack load.

Computation. We can readily compute the fraction of the ripple voltage which is dropped across each part of this a.c. voltage divider (across the choke coil and across the output filter condenser), assuming that the choke coil (L) has an inductance of 10 henrys, and the output filter condenser (C_o) has a capacity of 10 mfd. With the full-wave rectifier circuit employed in your power pack, the ripple frequency (f) is twice the power line frequency, or 120 cycles.

At the ripple frequency, the reactance of the output filter condenser will be:

$$X_o = 1{,}000{,}000 \div (6.28 \times f \times C_o)$$
$$X_o = 1{,}000{,}000 \div (6.28 \times 120 \times 10)$$
$$X_o = 1{,}000{,}000 \div 7{,}536 = 132 \text{ ohms}$$

Under the same conditions, the reactance of the choke coil will be:

$$X_L = 6.28 \times f \times L$$
$$X_L = 6.28 \times 120 \times 10 = 7{,}536 \text{ ohms}$$

These figures tell us that the reactance of the choke coil at the 120-cycle ripple frequency is about 57 times that of the output condenser (7,536 ÷ 132 = 57). This means that 56/57 of the total a.c. ripple voltage is dropped across the choke coil, and only 1/57 of the total (a negligible amount) is present across the output filter condenser and load. Since the a.c. ripple voltage at the filter input is rarely more than 7 volts even under full load, this means that the a.c. output voltage is negligibly small even when the load is increased to the maximum value which the power pack can safely handle.

We can compare reactances rather than impedances in this analysis simply because the d.c. resistance of the choke coil is negligibly small in comparison to its inductive reactance, and the condenser resistance is even smaller in comparison to its reactance.

Instructions for Report Statement No. 34. If you performed Experiment 34 slowly and carefully, so that you appreciated the full significance of each reading obtained, you will have no difficulty now in answering Report Statement No. 34 on the last page of this manual. In this report statement, you are simply asked to tell whether increasing the load on the d.c. output section of your power pack (by reducing the ohmic value of the load resistor) makes the a.c. ripple voltage across the input filter condenser decrease, increase or remain the same. Place a check mark after the answer you consider correct in the report statement.

EXPERIMENT 35

Purpose: **To prove that the inductance of the choke coil affects the a.c. ripple output voltage but does not affect the d.c. output voltage value, and to prove that the d.c. resistance of the choke coil affects the d.c. output voltage value.**

Step 1. To replace the choke coil in your power pack with a 200-ohm resistor, first unsolder the two wires which are on choke coil terminal *13*. Connect these two wires together with a temporary soldered hook joint, then bend the wires so that this joint does not touch terminal *13* or any other terminals. Now take your 200-ohm resistor (Part *3-4*) and connect one of its leads to choke coil terminal *14* with a temporary soldered lap joint. Connect the other resistor lead to the hook joint you just made, using either a soldered lap joint or a temporary soldered hook joint.

The change which you have just made is equivalent to removing the inductance of the choke coil while leaving its d.c. resistance in the circuit.

Step 2. To measure the d.c. output and the a.c. ripple voltages when the choke coil is replaced with a 200-ohm filter resistor and a 10,000-ohm load is connected to the d.c. output terminals, first take the group of four parallel-connected 40,000-ohm resistors left over from Experiment 34, and connect these to output terminals *4* and *5*.

With the power pack resting on its back side so that under-chassis connections are accessible, measure the d.c. output voltage between output terminals *4* and *5*, and record your result in Table *35* as the d.c. output voltage with a 200-ohm filter resistor and with a 10,000-ohm load.

Measure the a.c. voltage between terminals *4* and *5* for the same conditions, and record your result in Table *35* as the a.c. ripple voltage measured at the d.c. output terminals.

For comparison purposes, record in Table *35* the d.c. output voltage value which you measured in Experiment 32 for a 10,000-ohm load while the choke coil was still in the circuit (this is the first value which you recorded in Table *32*). Record also in Table *35* the a.c. ripple voltage in volts which you measured in Experiment 34 at the d.c. output terminals for a 10,000-ohm load and a 10-henry choke coil (the last reading you recorded in Table *34*).

Protecting N.R.I. Tester Against Surges. Always turn on the power pack before you turn on the N.R.I. Tester, and always turn off the N.R.I. Tester before you turn off the power pack. This prevents damage to the N.R.I. Tester by the voltage surges which exist at the instant of turning the power pack on or off. Be sure to turn off the power pack before touching the test clips with your fingers.

Step 3. To measure ripple and d.c. output voltages while the choke coil is replaced with a 200-ohm resistor and a 40,000-ohm load is connected to the d.c. output terminals, first remove three of the 40,000-ohm resistors from d.c. output terminals *4* and *5*, so as to leave only one 40,000-ohm resistor connected to these terminals. Now repeat each of the measurements made in Step 2; that is, measure the d.c. output voltage and the a.c. ripple voltage which is present at the d.c. output terminals, and record each measured value in Table *35*.

For comparison purposes, record also the d.c. and a.c. output voltages which you obtained in Experiments 32 and 34 respectively for a 40,000-ohm load and the original choke coil connection.

Discussion: A comparison of the two d.c. output voltage values which you recorded for Step 2 in Table *35* should prove definitely that the inductance of the choke coil has no effect upon the d.c. output voltage value. In other words, you should obtain essentially the same d.c. output voltage values when the 200-ohm resistor is in the circuit as when the choke coil was in the circuit during the 10,000-ohm load measurement in Experiment 32. Any difference between your values can be due to variations in line voltage or normal tolerances in radio part values.

A comparison of the d.c. output voltage values which you recorded in Step 3 of Table *35* for the 40,000-ohm load further verifies that the d.c. output voltage is independent of the amount of inductance in the choke coil.

When you study the a.c. output voltage values recorded for Step 2, however, you note an entirely different situation. When this was measured with a 10,000-ohm load and the choke coil in the circuit, in Step 2 of Experiment 34, zero voltage was obtained. When the choke coil is replaced with the 200-ohm resistor, however, an appreciable a.c. voltage value is present at the d.c. output terminals. This is definite proof that it is essentially the inductance of the choke coil (not the resistance) which keeps down the a.c. ripple voltage at the d.c. output terminals.

STEP	CIRCUIT DATA	D.C. OUTPUT VOLTAGE IN VOLTS		A.C. VOLTAGE IN VOLTS AT D.C. OUTPUT TERM.	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
2	10,000Ω LOAD AND 200Ω FILTER RESISTOR	340	350	2.8	2.4
	10,000Ω LOAD AND 10H. CHOKE COIL	340	350	2.5	0
3	40,000Ω LOAD AND 200Ω FILTER RESISTOR	380	420	2.5	1.2
	40,000Ω LOAD AND 10H. CHOKE COIL	380	420	2.1	0

TABLE 35. Record your results here for Experiment 35. All power pack measurements in this table are for normal full-wave rectification and condenser input. Values on the first line in each step are obtained with a 200-ohm resistor connected in place of the 10-henry choke coil. Values in the second line of each step in the table are obtained from Tables 32 and 34.

Making the same comparison for the 40,000-ohm load value in Step 3 further emphasizes the importance of the inductance in keeping down a.c. ripple.

Since the entire load current must flow through the choke coil or filter resistor, it should be apparent that the d.c. resistance of the choke coil will affect the d.c. output voltage. The greater the resistance of this choke coil, the greater will be the voltage drop across this coil and the less d.c. voltage there will be available at the d.c. output terminals.

You learned in connection with a previous experiment that the reactance of the choke coil is about 57 times the reactance of the output condenser (the computed values were 7,536 ohms and 132 ohms respectively). When you replace the choke coil with a resistor, however, you have only 200 ohms at the choke coil position acting in series with the output condenser reactance of 132 ohms. Under this condition, almost half of the input condenser ripple voltage is present across the output filter condenser and the load. This explains why you obtained measurable a.c. output voltage values at the d.c. output terminals when the choke coil was replaced by the 200-ohm resistor.

It is permissible to use a resistor in place of a choke coil in a filter circuit only when the ohmic value of the resistor is many times the reactance of the output filter condenser. A resistance value high enough for adequate filtering can be used only when the load voltage requirements are low or the load resistance is considerably higher than the required filter resistor value.

Instructions for Report Statement No. 35. The discussion for this experiment indicates that the ohmic value of the equivalent filter resistor affects both the d.c. output voltage value and the a.c. ripple voltage value. For this report statement, you will make additional measurements to verify these statements experimentally.

Remove the 200-ohm resistor which you connected between choke coil terminal *14* and the leads formerly on terminal *13*, and connect in its place a 20,000-ohm resistor (two of your 40,000-ohm resistors connected in parallel).

With a 40,000-ohm load still connected to the d.c. output terminals, measure the d.c. output voltage across the load (between terminals *4* and *5*). Compare this measured value with the d.c. output voltage value you obtained in Step 3 of this experiment for the same 40,000-ohm load and a 200-ohm resistor in place of the choke coil. Now turn to the last page of this manual, and answer the first half of Report Statement No. 35, wherein you are asked whether the d.c. output voltage increased, decreased or remained the same when you increased the ohmic value of the filter resistor from 200 ohms to 20,000 ohms.

Next, measure the a.c. ripple voltage value at the d.c. output terminals of your power pack while the same 40,000-ohm load and 20,000-ohm filter resistor are connected. Compare your measured value for this set-up with the measured ripple voltage value recorded for Step 3 in Table *35* for the 200-ohm filter resistor and 40,000-ohm load, then answer the last part of Report Statement No. 35.

If you keep in mind that you now have a 20,000-ohm resistance acting in series with the 132-ohm reactance of the output filter condenser, you should have no difficulty in figuring out the reason for the result you obtained when you measured the a.c. ripple voltage at the output terminals.

EXPERIMENT 36

***Purpose:* To determine how the filter system of your power pack performs when the input filter condenser is removed to give a choke input filter.**

Step 1. To secure a choke input connection, first remove the 20,000-ohm filter resistor which you used in place of the choke coil in the last experiment. Replace on choke coil terminal *13* the two wires which were originally on this terminal, so as to restore your power pack to its original circuit. Now disconnect the input filter condenser by unsoldering the lead which is on condenser terminal *29* and bend up this lead so it cannot touch other parts or terminals. Remove the 40,000-ohm load resistor from the d.c. output terminals.

Step 2. To measure the d.c. output voltage, the a.c. ripple output voltage, and the a.c. filter input voltage with no load on your power pack and with a choke input connection (with the input filter condenser removed), measure the d.c. voltage across terminals *4* and *5*, and record your result in Table *36* as the no-load d.c. output voltage.

Measure the a.c. ripple voltage at the d.c. output terminals *4* and *5*, and record your result in Table *36* as the a.c. voltage in volts at the d.c. output terminals of your power pack.

Measure the a.c. voltage across the 50,000-ohm bleeder resistor under the chassis, and record your result in Table *36* as the a.c. filter input voltage in volts.

Since there is no load in this step, there is no d.c. load current to measure. Simply record zero for this no-load current measurement in Table *36*.

Step 3. To measure the d.c. output voltage, a.c. ripple output voltage, the a.c. filter input voltage and the d.c. load current with a 40,000-ohm load and a choke input filter circuit, first take one of your 40,000-ohm resistors (Part *3-6A*) and connect it to output terminal screws *4* and *5*.

Measure the d.c. output voltage as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. ripple voltage at the d.c. output terminals as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. voltage at the input of the filter as instructed in Step 2, and record your result in Table *36*.

Prepare the N.R.I. Tester for direct current measurements according to previous instructions. Measure the d.c. load current in milliamperes by disconnecting the 40,000-ohm resistor lead from output terminal screw *4*, placing the red test clip on this re-

STEP	LOAD IN OHMS	D.C. OUTPUT VOLTAGE IN VOLTS		A.C. VOLTAGE IN VOLTS AT OUTPUT TERMINALS		A.C. FILTER INPUT VOLTAGE IN VOLTS		D.C. LOAD CURRENT IN MILLIAMPERES	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
2	NO LOAD	350	400	2.2	1.0	60	63	0	0
3	40,000	325	350	2.5	1.8	75	114	7.5	7
4	20,000	300	310	2.75	2.3	93	135	17.5	15
5	10,000	250	270	3.25	3.4	112	147		27

TABLE 36. Record your results here for Experiment 36. All power pack measurements in this table are for normal full-wave rectification and choke input.

sistor lead, and placing the black test clip on output terminal *4*. Record your result in Table *36* as the d.c. load current in milliamperes for a 40,000-ohm load.

Step 4. To repeat your series of four measurements with a 20,000-ohm load connected to the power pack, remove the test clips and reconnect the load resistor lead to output terminal screw *4*, then connect another 40,000-ohm resistor in parallel with this first one by means of temporary soldered lap joints so as to secure a 20,000-ohm load.

Measure the d.c. output voltage in volts as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. ripple output voltage in volts as instructed in Step 2, and record your result in Table *36*.

Measure the a.c. voltage at the input of the filter circuit as instructed in Step 2, and record your result in Table *36*.

Measure the d.c. load current in milliamperes as instructed in Step 3, and record your result in Table *36*.

Step 5. To repeat your series of four measurements with a 10,000-ohm load connected to the power pack, take your remaining two 40,000-ohm resistors and connect them in parallel with the two already on output terminals *4* and *5*, so that you have four parallel-connected 40,000-ohm resistors connected to these terminals to give a 10,000-ohm load. Now repeat each of the four measurements as instructed in Steps 2 and 3, and record your four results in Table *36*.

Step 6. To get a better picture of how load current varies with d.c. output voltage when the input filter condenser is disconnected, plot on Graph *32* the four sets of readings you just obtained for d.c. load current and d.c. output voltage. You received instructions in Experiment 32 for plotting values like these on a graph. Make heavy dots for each of your four points on the graph, then connect the dots together with a curve which passes through all four points. Label this as your curve for choke input, to distinguish it from the curve you previously drew for condenser input.

Discussion: Although it might be more convenient to start with a full load of 10,000 ohms and remove resistors one by one to reduce the load (as was done in Experiment 32), you follow normal laboratory procedure in this experiment by starting with no load and gradually increasing the load up to the maximum value. This procedure is preferred because there are occasions when you will not know whether some part in the circuit is capable of standing up under full-load conditions.

By starting with no load, you can at least get some of your readings before it is necessary to stop measurements because of overheating of a part. Sometimes the readings will indicate a tendency towards failure sufficiently in advance for you to stop the experiment and change the part or circuit to correct the condition. As far as actual values are concerned, you will secure the same readings regardless of whether you work from no load to full load or from full load to no load.

In this experiment, you remove the input filter condenser from your power pack circuit so as to duplicate the entirely possible condition whereby this condenser becomes defective during actual operation. When the input filter condenser is removed, the choke coil becomes the first part in the filter circuit through which the pulsating d.c. output of the rectifier tube passes. A filter circuit of this nature is commonly known as a *choke input filter,* while the original filter circuit in the power pack is known as a *condenser input filter*. Familiarity with the performance of a filter system having a defective input filter condenser will help you to recognize trouble of this type when you encounter it in radio equipment.

This experiment is important for still another reason. Although a choke input filter is rarely used in radio receivers, it is used extensively in transmitter power packs and in the high-voltage power packs of special radio apparatus. By becoming familiar with the operating characteristics of this type of filter, you acquire valuable training in these branches of radio as well as in radio receiver servicing.

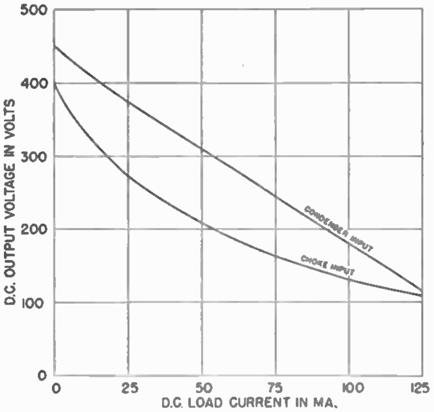


FIG. 15. Graph showing how the d.c. output voltages for condenser input and choke input in your power pack tend to become equal in value as the d.c. load current is increased up to the maximum safe current of 125 ma. which can be handled by the rectifier tube. Values for these curves can be obtained only by taking certain special precautions, because the power transformer and choke coil in your power pack are designed for maximum rated currents of only 25 ma. These current ratings are entirely ample for all experiments which you will perform with your power pack.

We can start our analysis of the results obtained in this experiment by considering the load current-d.c. output voltage curve which you plotted in Step 6. A comparison of this curve with that which you obtained in Experiment 32 shows immediately that the d.c. output voltage is lower for choke input than for condenser input. This is explained by the fact that with choke input, there is no input condenser to maintain the voltage in between the pulses of the rectifier tube output. The choke and output filter condenser merely serve to remove the a.c. component.

Voltage Regulation. To express how the output voltage of a power pack will drop when full load is applied, engineers often use a rating called *per cent voltage regulation*. This is obtained by taking the difference between the no-load and full-load voltages, dividing this difference by the no-load voltage value, then multiplying the result by 100.

There are certain special conditions in which choke input can give as good or even better voltage regulation than condenser input. For instance, the d.c. output voltage of the power pack was measured in the N.R.I. laboratory with various load values drawing up to 125 ma., using both choke input and condenser input, and the results plotted to give the curves shown in Fig. *16*. These curves show that with a 125-ma. load, the d.c. output voltages become very nearly equal for both curves.

Careful examination of the curves in the vicinity of 125 ma. shows that variations in load current in this region will cause less variation in the d.c. output voltage when choke input is used than when condenser input is used. In other words, the choke input curve is flatter than the condenser input curve at high load-current values. This verifies the statements made in your regular lessons regarding the advantages of choke input in power packs which must supply high d.c. output voltages to large varying loads, such as in the power packs of transmitters.

The curves in Fig. *16* give the voltage regulation of the entire power pack, including the power transformer. If a sufficiently large power transformer were used to eliminate the voltage regulation characteristics of the power transformer from these curves, the superiority of the choke input filter over the condenser input filter at high load current values would be much more evident.

Ripple Voltage. An examination of the a.c. voltage values which you recorded in Table *36* shows that both the input a.c. voltage to the filter and the a.c. ripple output voltage are much higher with choke input than they were for the corresponding measurements made in Experiment 34 with condenser input and recorded in Table *34*.

In the discussion of Experiment 34, we calculated that the ripple voltage was reduced about 57 times by the choke coil and output filter condenser. In the case of choke input, we can determine the ripple reduction factor for each load simply by dividing the filter input a.c. voltage by the filter output a.c. voltage.

The N.R.I. values of a.c. voltage and the resulting ripple reduction factors have been reproduced in Fig. *16* for your convenience in analyzing the results. Now we can see that for a 40,000-ohm load the ripple reduction is 63. With a 20,000-ohm load it drops slightly, down to 59, and with a 10,000-ohm load it drops down to 43. This change in the ripple reduction factor is due to the fact that the inductance of the choke coil drops as the direct current flowing through the choke coil increases.

LOAD IN OHMS	N.R.I. VALUE OF A.C. FILTER INPUT VOLTAGE IN VOLTS	N.R.I. VALUE OF A.C. FILTER OUTPUT VOLTAGE IN VOLTS	RIPPLE REDUCTION FACTOR
40,000	114	1.8	63
20,000	135	2.3	59
10,000	147	3.4	43

FIG. 16. N.R.I. values for the a.c. filter input and output voltages obtained in Experiment 36 have been repeated here for convenience in analyzing them, along with the computed ripple reduction factor values for each load resistance. The ripple reduction factor is obtained by dividing the a.c. filter input voltage for a given load by the a.c. filter output voltage obtained at that same load.

The values in Fig. *16* show clearly that the a.c. input voltage to the filter goes up as load is applied, and the a.c. ripple voltage in the d.c. output likewise increases with load. This means that you should expect to secure increased hum when you increase the load acting on a power pack in a radio receiver. A common receiver defect illustrating this characteristic is that in which a partial short circuit is developed across the power pack by failure of some part in the receiver. The increased load pulls down the output voltage, thereby reducing the volume of the reproduced program, and at the same time the increased a.c. voltage in the output produces a hum in the loudspeaker.

A comparison of the results obtained in this choke input experiment with those obtained previously for condenser input tells you what symptoms can be expected if the input condenser in a radio receiver power pack becomes defective. First of all, hum will be noticeable, for the opening of the input condenser gives a choke input filter circuit, and this delivers a higher a.c. ripple voltage to the load. Furthermore, unless the power pack happens to be operating very near the current limit of the rectifier tube (a condition rarely encountered in radio receivers), the opening of the input condenser *will make the d.c. output voltage drop*, causing reduced volume and reduced receiver sensitivity.

Instructions for Report Statement No. 36. In this experiment, you demonstrated a number of important characteristics of radio receiver power packs. Among other things, you learned that the opening or removal of the input filter condenser changes your filter circuit from condenser input to choke input, with the result that both the d.c. output voltage and the a.c. ripple output change.

To test your understanding of what you measured and studied in the experiment, you are asked in Report Statement No. 36 to specify whether the d.c. output voltage increases, decreases or remains the same when the input filter condenser of your power pack opens up while connected to a 10,000-ohm load (equivalent to changing from condenser input to choke input). Place a check mark after the answer you consider correct.

EXPERIMENT 37

Purpose: **To demonstrate that half-wave rectification gives a lower d.c. output voltage and a higher a.c. ripple output voltage than does full-wave rectification.**

Step 1. To convert your power pack circuit to a form which provides half-wave rectification, simply open the plate connection to one section of the rectifier tube by unsoldering the lead which is on socket terminal *4* and bending this lead up so that it cannot touch other terminals or parts. Leave other power pack connections as they were for the preceding experiment, so that you have a choke input filter (leave the lead still disconnected from condenser terminal *29*). Check the calibration of the N.R.I. Tester in the usual manner.

Step 2. To measure the d.c. and a.c. ripple output voltages for no load when the power pack is connected for choke input and half-wave rectification, measure the d.c. voltage between output terminals *4* and *5*, and record your result in Table *37* as the d.c. output voltage in volts for no load.

Measure the a.c. voltage between terminals *4* and *5*, and record your result in Table *37* as the a.c. ripple output voltage for no load.

Step 3. To measure the d.c. and a.c. ripple output voltages for a 40,000-ohm load when the power pack is connected for choke input and half-wave rectification, measure in turn the d.c. output voltage and the a.c. ripple output voltage of your power pack with a 40,000-ohm resistor connected to output terminals *4* and *5*. Follow exactly the same procedures specified in Step 2, and record your results in Table *37*.

Step 4. To measure the d.c. and a.c. ripple output voltages for a 10,000-ohm load when the power pack is connected for choke input and half-wave rectification, connect all four of your 40,000-ohm resistors in parallel to output terminals *4* and *5* in exactly the same manner you did for previous experiments, then measure in turn the d.c. output voltage and the a.c. ripple output voltage of your power pack by following the measuring procedures specified in Step 2, and record your results in Table *37*.

Discussion: Careful comparison of the results you obtained with corresponding load values recorded in Table *36* for choke input and *full-wave* rectification should show that half-wave rectification gives *lower d.c. output voltage* and *higher a.c. ripple output voltage* than does full-wave rectification. For example, with choke input and no load, the N.R.I. value of output voltage is 350 volts for half-

STEP	LOAD IN OHMS	O.C. OUTPUT VOLTAGE IN VOLTS		A.C. OUTPUT VOLTAGE IN VOLTS	
		YOUR VALUE	N.R.I.	YOUR VALUE	N.R.I.
2	NO LOAD	310	350	2.8	2.3
3	40,000	280	300	3.8	4.5
4	10,000	210	210	7.2	9.3

TABLE 37. Record your results here for Experiment 37. All power pack measurements in this table are for half-wave rectification and choke input.

wave rectification in Table *37*, and 400 volts for full-wave rectification in Table *36*. On no load, the a.c. ripple output voltage is 2.3 volts for half-wave rectification and only 1 volt for full-wave rectification.

The same factors which make the d.c. output voltage drop when half-wave rectification is employed also serve to make the a.c. output increase. First of all, with half-wave rectification only one alternation of each cycle of the a.c. secondary voltage of the power transformer is sending current through the rectifier tube. This is indicated by the filter input voltage wave shown in Fig. *17*. The filter input voltage is at zero for such a high proportion of the total time that the average d.c. voltage at the filter input is quite low for half-wave rectification.

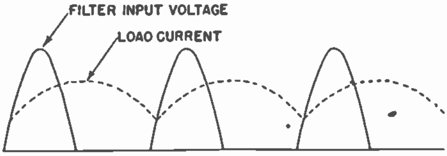


FIG. 17. Curves showing the wave form of the filter input voltage and the load current in an a.c. power pack employing half-wave rectification.

Fortunately, the choke coil prevents the load current from following too closely the fluctuations in the input voltage. The choke tends to oppose changes in the current passing through it, and consequently the load current has a wave form like that shown by the dash-dash load current curve in Fig. *17*. This is far from being a pure d.c. output, indicating that additional filtering would be needed in your power pack if it were permanently connected for choke input and half-wave rectification.

Another factor which makes half-wave rectification have a high a.c. ripple output is the fact that the fundamental ripple frequency for half-wave rectification is only 60 cycles, as compared to 120 cycles for full-wave rectification. Cutting the frequency in half cuts the reactance of the choke coil in half and doubles the reactance of the output filter condenser. As a result, the ripple reduction factor of the choke coil-output condenser combination is reduced 4 times. Dividing 57 by 4 gives only 14 as the ripple reduction factor when we have a 10-henry choke and 10-mfd. output condenser.

Instructions for Report Statement No. 37. So far, all of your measurements for half-wave rectification have been made with a choke input filter. To determine the effect of additional filtering upon the d.c. output voltage and the a.c. output voltage while using half-wave rectification, reconnect the input filter condenser lead to condenser terminal *29* to secure condenser input again, and repeat the series of two measurements which you made for a 10,000-ohm load in Step 4 of this experiment. Compare the d.c. output voltage value which you obtain for this condenser input measurement with that which you recorded in Table *37* for the 10,000-ohm load, then turn to the last page and answer the first half of Report Statement No. 37.

Next, compare the a.c. output voltage value which you just measured for condenser input with that which you obtained for choke input and a 10,000-ohm load in Step 4, and answer the last part of Report Statement No. 37.

Now, if you analyze your answers to this report statement, you should be able to figure out why a condenser input filter is always used in radio receiver power packs employing half-wave rectification.

Be sure to turn off the N.R.I. Tester and the power pack after completing these measurements. Leave the 10,000-ohm load connected to the power pack, since you will use this in the next experiment.

EXPERIMENT 38

***Purpose:* To demonstrate that the a.c. ripple output voltage can be reduced by tuning the choke coil with a suitable shunt condenser value.**

Step 1. To tune the choke coil in your power pack approximately to resonance, take the two .25-mfd. paper condensers (Parts *3-2A* and *3-2B*), connect one in parallel with the other by means of temporary soldered joints, then connect the combination in parallel with the choke coil (across terminals *13* and *14*) by means of temporary soldered lap joints. Now disconnect the lead from condenser terminal *29* so as to secure choke input again, and check output terminals *4* and *5* to be sure the 10,000-ohm load is still connected properly to these terminals. Leave the wire disconnected from socket terminal *4* to provide half-wave rectification.

A.C. RIPPLE VOLTAGE IN VOLTS AT D.C. OUTPUT TERMINALS	
YOUR VALUE	N.R.I. VALUE
3.7	7.2

TABLE 38. Record your result here for Experiment 38. The measurement is made with half-wave rectification, choke input, a 10,000-ohm load, and a .5-mfd. condenser connected to tune the choke coil approximately to resonance.

Measure the a.c. ripple output voltage at d.c. output terminals *4* and *5*, and record your result in Table *38*.

Discussion: In an earlier experiment, you made measurements which showed that a .5-mfd. condenser will tune your 10-henry choke coil approximately to resonance at 60 cycles. Furthermore, you learned in your regular course that at resonance, a parallel resonant circuit has a much higher impedance than does the coil or condenser alone. You utilize all this information in a highly practical manner in this experiment by placing the .5-mfd. condenser across your choke coil, while the power pack is connected for half-wave rectification, choke input and a 10,000-ohm load.

As Table *38* indicates, an a.c. voltage value of 7.2 volts was obtained in the N.R.I. laboratory for this particular measurement. Comparing this value with the corresponding value obtained for a 10,000-ohm load, half-wave rectification and choke input in Table *37* (where the choke was not tuned), it is apparent that tuning the choke coil lowers the a.c. ripple output considerably.

Tuning of the filter choke coil is by no means a complete solution to the filtering problem in a half-wave rectifier, or even in a full-wave rectifier, but it does improve the filtering sufficiently to warrant its use in many radio receiver power packs. Whenever you encounter a receiver power pack in which a condenser is connected across the choke coil, you can be sure the condenser is there for the purpose of tuning the choke coil.

When tuning of the choke is incorporated in the power pack of a commercial radio receiver during design, the choke coil itself is designed to have a low a.c. resistance, so as to make its Q factor high. With a high Q factor, the impedance of the coil can be stepped up many times by tuning it to resonance, thus reducing the ripple output considerably. The 10-henry choke coil employed in your power pack has a relatively low Q factor, for it is designed primarily for use in ordinary condenser input filters where the Q factor is unimportant.

When excessive hum is encountered in a receiver which has a tuned choke coil in its power pack filter system, the condenser used across the choke coil should be checked carefully. If this condenser is open or is excessively leaky, there will be little or no impedance step-up, and the a.c. ripple or hum output will be high.

Sometimes a mechanical shock such as dropping a receiver will alter the positions of the laminations in the choke coil, thereby changing the inductance of the choke coil; in this case, a new choke or a different capacity value may be needed in order to produce resonance and eliminate hum.

Instructions for Report Statement No. 38. A .5-mfd. capacity gave a decided decrease in the hum output when connected across the choke coil; will an even greater reduction in hum be obtained with a .25-mfd. condenser, will the hum remain the same, or will you get more hum than with the .5-mfd. capacity? This is the problem in Report Statement No. 38.

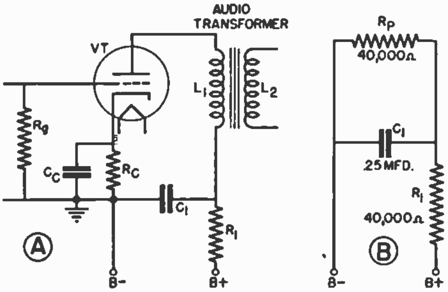


FIG. 18. Schematic circuit diagram of a typical audio amplifier stage (*A*), and the equivalent circuit diagram (*B*) which you set up to duplicate the loading effect of this stage upon a power pack to which it is connected.

In order to answer this question, remove one of the .25-mfd. condensers which you connected across the choke coil, so that only .25 mfd. is in parallel with the choke, then repeat your measurement of the a.c. ripple voltage at the d.c. output terminals.

Compare your measured value with that which you recorded in Table *38* for the .5-mfd. condenser, then turn to the last page and place a check mark after the answer which describes your result. Finally, remove the .25-mfd. condenser which you placed across the choke coil.

EXPERIMENT 39

Purpose: **To demonstrate the effectiveness of a resistor-condenser filter in reducing a.c. ripple voltage.**

Preliminary Discussion: In Fig. *18A* is shown a typical audio amplifier circuit such as might be found connected to a power pack like yours in an actual radio receiver. The terminals marked $B-$ and $B+$ in this circuit would go to the $B-$ and $B+$ terminals respectively of the power pack.

As you have already demonstrated in previous experiments, a power pack may supply a small a.c. ripple voltage value along with its normal d.c. output voltage. If this ripple voltage is allowed to affect the plate circuit of a stage like this, it will produce a corresponding hum frequency in the signal output (across primary winding L_1 of the audio transformer).

Resistor R_1 and condenser C_1 in Fig. *18A* form a filter which effectively prevents power pack a.c. ripple from entering the plate circuit. The a.c. voltage between the $B-$ and $B+$ terminals in Fig. *18A* is divided between C_1 and R_1, with most of the a.c. voltage being dropped across R_1. In designing a circuit like this, the reactance of C_1 is made very low in comparison to the resistance of R_1, so that only a negligibly small a.c. voltage is developed across C_1 for application to the plate circuit.

With your power pack, you can readily duplicate the conditions existing in the circuit of Fig. *18A*, and demonstrate to yourself the effectiveness of a resistor-condenser filter in reducing power pack hum or a.c. ripple. It is not necessary to use the entire vacuum tube circuit shown in Fig. *18A* for this experiment, because we can satisfactorily duplicate this circuit with two resistors and a condenser arranged as shown in Fig. *18B*. Here C_1 and R_1 are the same as in Fig. *18A*, but R_P is a 40,000-ohm resistor which essentially duplicates the total plate circuit resistance of a typical vacuum tube circuit (such as a circuit having a plate voltage of 250 volts and a plate current of 6.25 ma., corresponding to a total circuit resistance of 250 ÷ .00625, or 40,000 ohms).

By setting up the circuit shown in Fig. *18B*, connecting the $B-$ and $B+$ terminals of the circuit to the corresponding terminals of your power pack, and measuring the a.c. ripple voltage first at the power pack output terminals (at the input of our resistor-condenser filter R_1-C_1), then across equivalent load resistor R_P (across the output of filter R_1-C_1), we can readily compute the ripple reduction factor of this filter combination.

Step 1. To set up the apparatus necessary for demonstrating the effectiveness of resistor-condenser filter R_1-C_1 in Fig. 18B, first connect a 20,000-ohm load to d.c. output terminals *4* and *5* by placing two of your 40,000-ohm resistors in parallel across these terminals in the manner shown in Fig. *19*. Arrange the resistors so that they rest on the table or bench top. Leave the power pack connected for half-wave rectification and choke input just as it was at the end of the preceding experiment, so that with this circuit combination and the 20,000-ohm load you are obtaining a fairly high a.c. ripple output along with the d.c. output.

Next, connect the remaining two 40,000-ohm resistors and a .25-mfd. condenser (Part *3-2A*) between output terminals *4* and *5* exactly as shown in Fig. *19*, allowing these resistors also to rest upon the table or bench top. Make temporary soldered joints in all cases.

Step 2. To measure the a.c. ripple voltage at the input of filter R_1-C_1, place the red test clip on any resistor lead going to output terminal *5*, place the black test clip on any resistor lead going to output terminal *4*, measure the a.c. voltage, and record your result in Table *39* as the a.c. ripple voltage in volts at the input of filter R_1-C_1.

To measure the a.c. ripple voltage at the output of filter R_1-C_1 (across C_1), simply move the red clip to the common junction of C_1, R_1 and R_P (Fig. *19*), leaving the black clip on a lead going to terminal *4*. Record your result in Table *39* as the a.c. ripple voltage in volts at the output of filter R_1-C_1.

A.C. RIPPLE VOLTAGE IN VOLTS AT INPUT OF FILTER R_1-C_1		A.C. RIPPLE VOLTAGE IN VOLTS AT OUTPUT OF FILTER R_1-C_1	
YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
6.0	6.9	1.1	1.1

TABLE 39. Record your results here for Experiment 39. The measurements are for half-wave rectification, choke input, and a 20,000-ohm load connected to the d.c. output terminals of the power pack.

Discussion: You can determine the ripple reduction factor of your resistor-condenser filter R_1-C_1 simply by dividing the a.c. filter input voltage by the a.c. filter output voltage.

If we do this with the N.R.I. values, we obtain a filter reduction factor of approximately 6. (6.9 ÷ 1.1 = 6.2). If you secure approximately this ripple reduction factor with your values, you have proved experimentally that a resistor-condenser filter of this type will definitely reduce hum voltages.

The theoretical ripple reduction factor of an R-C filter can very readily be computed. With half-wave rectification, the ripple frequency is 60 cycles. At this frequency, a .25-mfd. condenser will have a reactance of 10,600 ohms.*

With a value of 40,000 ohms for filter resistor R_1, the a.c. voltages will divide in the

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*$X_C = \frac{1,000,000}{6.28 \times .25 \times 60}$

$X_C = 10,600$ ohms

ratio of 40,000 to 10,600, which is approximately 3.77. This value will then be the theoretical ripple reduction factor. The shunting effect of 40,000-ohm resistor R_P on the condenser lowers the reactance between the condenser terminals, thus increasing the ripple reduction factor of the circuit. The measured N.R.I. value of 6 is, therefore, entirely acceptable.

A.F. Filtering Action. A resistor-condenser filter (usually called simply an R-C filter) in the plate circuit of a radio receiver also serves to prevent a.f. signals in the plate circuit from entering the power pack and traveling from there to other circuits where undesirable regeneration or degeneration might be produced. Thus, filter condenser C_1 in the vacuum tube circuit of Fig. *18A* has a reactance which is low with respect to the total impedance of the signal path through vacuum tube *VT*, coil L_1 and the parallel combination of cathode resistor R_C and C_C, and hence only a small portion of the total available a.f. voltage exists across C_1 to feed back into the power pack.

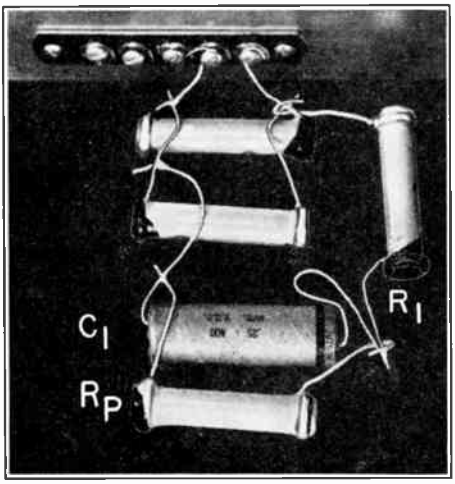

FIG. 19. Suggested method of connecting to the d.c. output terminals of your power pack a 20,000-ohm load and an arrangement of two resistors and a condenser (R_1, R_P and C_1) which duplicates the effect of a typical audio amplifier stage having an R-C filter and a total plate circuit resistance of 40,000 ohms.

R_1 in Fig. *18A* acts with the output filter condenser in the power pack as an R-C filter for a.f. signals heading in this opposite direction toward the power pack. The reactance of the output filter condenser is usually quite low at audio frequencies (is less than 200 ohms), while R_1 is generally higher than 10,000 ohms in value, so that the ripple reduction factor for a.f. signals heading toward the power pack is considerably higher than 50.

Instructions for Report Statement No. 39. Experiment 39 proved conclusively that an R-C filter connected between the power pack and a load will reduce the a.c. ripple filter voltage which reaches the load. One question still remains unanswered, however: Does the insertion of an R-C filter between source and load affect the value of the d.c. voltage applied to the load?

You will recall that resistor R_P in Fig. *18B* serves to duplicate the plate circuit resistance of an audio amplifier stage. Our question really asks, then, whether the voltage across R_P is any different from the voltage between the $B-$ and $B+$ terminals in Fig. *18B*. This can be checked very easily by making two simple d.c. voltage measurements in your test circuit. Once you make these measurements and compare your readings, you will have no difficulty in answering Report Statement No. 39.

To measure the d.c. output voltage of your power pack, simply place the red clip on output terminal *5*, place the black clip on output terminal *4* (while leaving all four resistors and the condenser connected to these terminals in the manner shown in Fig. *19*), measure the d.c. voltage, and make a notation of your result in the margin of this page or elsewhere.

Next, measure the d.c. voltage across 40,000-ohm load resistor R_P by placing the red clip on the common junction of leads from R_P, C_1 and R_1 and leaving the black clip on output terminal *4*. Record this value also in the margin of this page. Compare your two measured values of d.c. voltage, then turn to the last page and place a check mark after the answer which best describes your conclusions regarding these measurements. Unsolder R_1, R_P and C_1 in Fig. *19*, but leave the other two 40,000-ohm resistors connected to the d.c. output terminals of the power pack.

EXPERIMENT 40

Purpose: **To show that resistance in series with a filter condenser increases the amount of ripple voltage at the output of a power pack.**

Step 1. To connect your power pack for full-wave rectification with condenser input, with a 1,000-ohm resistance in series with the input filter condenser, and with a 10,000-ohm load connected to the d.c. output terminals of the power pack, first restore full-wave rectification by reconnecting the transformer secondary lead to socket terminal *4*. Next, take a 1,000-ohm resistor (Part *3-5A*), connect one of its leads to electrolytic condenser terminal *29* by means of a temporary soldered hook joint, and connect the other resistor lead to the wire from choke coil terminal *14* which formerly went to condenser terminal *29*, as indicated by the circuit diagram in Fig. *20A*. Adjust the position of the 1,000-ohm resistor so that none of its leads are touching other uninsulated leads or terminals.

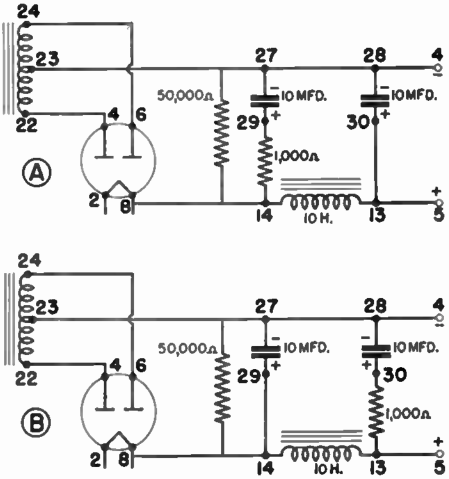

FIG. 20. Simplified schematic circuit diagrams of your a.c. power pack when connected normally for full-wave rectification and condenser input, showing how a 1,000-ohm resistor is to be inserted in series with each 10-mfd. electrolytic filter condenser in turn to duplicate the effect of a dried-out filter condenser.

240
110

Place a 10,000-ohm load across output terminals *4* and *5* by soldering the remaining two 40,000-ohm resistors in parallel with the two 40,000-ohm resistors already connected to these terminals.

Step 2. To measure the input and output a.c. voltages of the filter system in your power pack when a 1,000-ohm resistor is in series with the input filter condenser, first measure the a.c. voltage across the 50,000-ohm bleeder resistor, and record your result in Table *40* as the a.c. ripple voltage in volts at the input of the filter when a 1,000-ohm resistance is in series with the input filter condenser.

Measure the a.c. voltage between output terminals *4* and *5* for the same conditions, and record your result in Table *40* as the a.c. ripple in volts at the output of the filter when you are using a 1,000-ohm resistor in series with the input filter condenser.

Measure the d.c. output voltage of the power pack, and record your measured d.c. output voltage value in Table *40*.

Step 3. To secure a.c. ripple voltage readings at the input and output of the filter when a 1,000-ohm resistor is in series with the output filter condenser, first remove the 1,000-ohm resistor from the power pack circuit and reconnect choke coil terminal *14* directly to condenser terminal *29*. Now unsolder the lead which is on condenser terminal *30*, connect one lead of the 1,000-ohm resistor to terminal *30*, and connect the other resistor lead to the lead which you just unsoldered from *30*. This places the 1,000-ohm resistor in series with the *output* filter condenser, as shown in Fig. *20B*.

Measure the a.c. voltage across the 50,000-ohm bleeder resistor, and record your result in Table *40* as the a.c. ripple in volts at the input of the filter when using a 1,000-ohm resistor in series with the output filter condenser.

Measure the a.c. voltage at output terminals *4* and *5*, and record your result in Table *40* as the a.c. ripple in volts at the filter output.

Measure the d.c. output voltage now, and record your result in Table *40*.

Discussion: It is entirely possible for an electrolytic condenser to dry out during use, so that it becomes equivalent to a condenser in series with a resistor. When this condition is sufficiently serious, hum becomes noticeable along with radio programs; in certain cases, the d.c. output voltage may drop, so that the receiver loses sensitivity (ability to reproduce programs of distant or weak stations satisfactorily), and the reproduced program becomes distorted due to low operating voltages.

In this experiment, you introduce in series with each electrolytic filter condenser in turn a 1,000-ohm resistor which duplicates the condition whereby the electrolytic condenser has dried out.

The N.R.I. values given in Table *40* for Step 2 indicates an a.c. filter input voltage of 33 volts, as compared to only 6.3 volts for the corresponding N.R.I. measurement in Step 2 of Table *34* when no resistor was in series with the input filter condenser. This is quite a large difference, but when we compare the N.R.I. values for the a.c. ripple output, the difference is very much less. Thus, the N.R.I. value is 1 volt in Table *40* and zero in Table *34*.

This indicates that a defective input filter condenser will increase the amount of a.c. input to the filter, but the output filter condenser and choke coil together will prevent most of this a.c. ripple from entering the load. The resistance acting in series with the input filter condenser prevents this condenser from charging and discharging fast enough to hold up the filter input voltage in between peaks of the rectified output.

The N.R.I. d.c. output voltage of 325 volts for Step 2 in Table *40* is comparable with the N.R.I. value of 350 volts for a 10,000-ohm load in Table *32*. This indicates that drying out of the *input* filter condenser will cause some decrease in the d.c. output

STEP	CIRCUIT DATA	A.C. RIPPLE IN VOLTS AT INPUT OF FILTER		A.C. RIPPLE IN VOLTS AT OUTPUT OF FILTER		D.C. OUTPUT VOLTAGE IN VOLTS	
		YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE	YOUR VALUE	N.R.I. VALUE
2	1000Ω IN SERIES WITH INPUT FILTER CONDENSER	35	33	1.1	1.0	300	325
3	1000Ω IN SERIES WITH OUTPUT FILTER CONDENSER	6.3	6.3	2.4	2.1	340	350

TABLE 40. Record your results here for Experiment 40. All power pack measurements in this table are for normal full-wave rectification and condenser input, with a 10,000-ohm load connected to the d.c. output terminals of the power pack.

voltage, resulting in lowered output volume, loss of sensitivity, and possibly also in distortion.

When the 1,000-ohm resistor is placed in series with the output filter condenser to simulate a defect in this condenser, the N.R.I. value of 6.3 volts in Step 3 of Table *40* is the same as the value of 6.3 volts for the corresponding condition without the 1,000-ohm resistor in Step 2 of Table *34*. The a.c. ripple output at the d.c. output terminals is quite high, however, when the resistor is present; it is 2.1 volts in Step 3 of Table *40*, but zero in Table *34*. This indicates that drying out of the output filter condenser will definitely cause appreciable hum in a radio receiver.

Considering the d.c. output values for Step 3 of Table *40* and for the 10,000-ohm load condition in Table *32*, we find that exactly the same values were obtained in both cases. This indicates that loss of capacity in the output filter condenser will have no effect upon the d.c. output voltage. Actually, you can disconnect the output filter condenser without affecting the d.c. output voltage.

Apparently it is the output filter condenser which has the most control upon the amount of ripple in the a.c. output. Let us consider why this is so. At 120 cycles (the ripple frequency in the full-wave rectifier circuit we are now employing), the reactance of a 10-mfd. condenser is about 132 ohms. The insertion of a 1,000-ohm resistor in series with 132 ohms will make the combination essentially resistive, having a total impedance only slightly higher than 1,000 ohms. The impedance of the output filter condenser is now much closer to the impedance of the choke coil, with the result that the ripple reduction factor is greatly reduced.

Drying out of the output filter condenser creates another serious condition in a practical radio circuit. As you will recall, this condenser acts with the series resistor in the plate supply lead of each vacuum tube stage as an R-C filter which prevents a.f. plate current from entering the power pack. A reduction in the capacity of the output filter condenser reduces considerably the effectiveness of this R-C filter, with the result that a.f. and r.f. currents may enter the power pack and travel from there to other circuits, causing serious regeneration or degeneration which is evident as howling. low volume or distortion.

Instructions for Report Statement No. 40. In the discussion, we pointed out that a reduction in the capacity of the output filter condenser has essentially no effect upon the value of the d.c. output voltage. This means that there will be essentially no change in the d.c. output if one lead of the output filter condenser in a radio receiver should accidentally break or open. But what will happen to the a.c. ripple voltage at the output of the filter when this occurs? By disconnecting one lead of the output filter condenser, then measuring this a.c. ripple voltage, you can answer this question for yourself and at the same time secure the information needed to answer Report Statement No. 40.

You should still have the 1,000-ohm resistor connected in series with the output filter condenser. Unsolder this resistor from the circuit, but leave this condenser still disconnected. Now measure the a.c. ripple output voltage at output terminals *4* and *5*, and record your result in Report Statement No. 40.

Now, for your own information, compare this measured value with that which you recorded in Step 2 of Table *34* for the corresponding conditions with the output filter condenser connected (your value will be under the column in Table *34* headed *A.C. VOLTAGE IN VOLTS AT D.C. OUTPUT TERMINALS*).

Important Instructions. Restore your power pack to its original circuit by reconnecting the lead from choke coil *13* back on condenser terminal *30*. Check the wiring of your power pack now against the semi-pictorial wiring diagram in Fig. *8*, to be sure that all connections are correct. If you desire, you can now convert all temporary hook joints to permanent hook joints by squeezing the hooks with long-nose pliers while keeping the solder molten on the joint with your soldering iron.

Finally, make a check of the no-load d.c. output voltage of your power pack to be sure it is operating properly. The voltage which you measure now should correspond to that which you recorded for Step 1 in Table *31*. Be sure to turn off the N.R.I. Tester and the power pack when you have finished your work.

NOTICE: Remember that during all work with your a.c. power pack, the short length of bare wire should be left between terminals *3* and *4*, exactly as instructed in this manual, and an external ground connection should always be made to terminal *3* or *4* whenever using the power pack.

Detach by Cutting Along This Line. Do Not Tear Off.

INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 21 TO 30

3 RK-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

A COURSE IN PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

THE UNKNOWN FUTURE OF RADIO

In the short period of approximately twenty years, radio has brought innumerable benefits to mankind. Continents have been drawn together, new cultural avenues have been opened up to rich and poor alike, entertainment has been brought to shut-ins, advertising methods have been revolutionized, and education of large audiences has been made possible.

But these are only a few of radio's achievements. Twenty-four hours a day in city or country, during hurricanes, floods and disasters on land or sea, radio brings help to those in distress. In the air, radio beam highways guide airplanes safely along their routes through storm, fog and darkness.

With 110,000,000 listeners and with hundreds of millions of dollars being spent yearly to provide programs, radio ranks first in American life. From breakfast to bedtime, broadcast band and short-wave stations alike pour forth entertainment, news, education and advertising, for all who own radio receivers and want to listen.

And yet today is only the beginning. Short-wave radio uses are expanding rapidly. Television, frequency modulation and electronic musical instruments are all taking on commercial status. Soon these and many more new services will be bringing even more startling marvels of sound and sight into American homes.

Yes, we have seen only the beginning of radio. Its unknown future for the years ahead is by far radio's greatest asset. And radio's future is *your future.*

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 21 to 30

Introduction

A PRACTICAL radio circuit consists of one or more sources of e.m.f. and one or more radio parts like resistors, coils and condensers. In every radio circuit, no matter how simple or how complex it may be, the distribution of voltages and currents is quite definite and is governed by three simple electrical laws. In the early lessons of your fundamental course, you learned that these three basic laws are: *1. Ohm's Law; 2. Kirchhoff's Current Law; 3. Kirchhoff's Voltage Law.*

To appreciate the actions which take place in a radio receiver, radio transmitter or other radio device, it is essential that you have a clear understanding of these three laws. In this manual, therefore, you will make a number of practical demonstrations which will illustrate each of these laws and convince you of their reliability.

The three basic electrical laws can be applied to any radio circuit whatsoever. With a.c. circuits, however, capacitive reactance and inductive reactance must be taken into account along with resistance. For this reason, it is convenient to use two forms of each law, one for d.c. circuits and the other for a.c. circuits. The laws are given below for reference purposes.

Ohm's Law for D.C. Circuits. **The current (I) flowing through a d.c. circuit is directly proportional to the voltage (E) acting in the circuit, and is inversely proportional[*] to the *resistance* (R) of the circuit. Formula: $I = E \div R$.**

Ohm's Law for A.C. Circuits. **The current (I) flowing through an a.c. circuit is directly proportional to the voltage (E) acting in the circuit, and is inversely proportional to the *impedance* (Z) of the circuit. Formula: $I = E \div Z$.**

Kirchhoff's Current Law for D.C. Circuits. **In any d.c. circuit, the *arithmetical* sum of the currents flowing to a point in the circuit is equal to the *arithmetical* sum of the currents flowing away from that point.**

Kirchhoff's Current Law for A.C. Circuits. **In any a.c. circuit, the *vector* sum of the currents flowing to a point in the circuit is equal to the *vector* sum of the currents flowing away from that point.**

Kirchhoff's Voltage Law for D.C. Circuits. **In any d.c. circuit, the *arithmetical* sum of the voltage sources acting in any one complete electron path is equal to the *arithmetical* sum of the voltage drops in that electron path.**

Kirchhoff's Voltage Law for A.C. Circuits. **In any a.c. circuit, the *vector* sum of the voltage sources acting in any one complete electron path is equal to the *vector* sum of the voltage drops in that electron path.**

Observe that the only difference between the d.c. and a.c. forms of Kirchhoff's two laws is the fact that we consider *arithmetical* sums in d.c. circuits (we add the voltage and current values together directly while taking their signs into account), while in a.c. circuits we must consider *vector* sums of the currents or voltages under consideration (we must consider phase relationships when combining the voltages or currents).

In d.c. circuits, resistance is the only thing which offers opposition to electron flow; voltage drops across resistors and currents through resistors are always in phase with each other, and hence voltage values or current values can be added or subtracted directly in d.c. circuits.

In a.c. circuits, we have inductive reactance and capacitive reactance

---

[*] Inversely proportional means that an *increase* in one quantity causes a corresponding proportional *decrease* in another quantity.

offering opposition to electron flow along with resistance, and consequently the currents in various parts of the circuit will have a definite *phase* relationship with each other. Likewise, the a.c. voltages under consideration will have a definite *phase* relationship with each other, making it necessary that we consider phase relationships by combining the values vectorially.

Purpose of Experiments in This Manual. Ohm's Law and Kirchhoff's Laws together constitute the foundation of all electrical and radio circuits. Without these three laws, engineers would be unable to design circuits or locate faults in circuits. Therefore, as a prospective Radiotrician you must have a clear understanding of how voltages and currents distribute themselves in circuits according to these laws. You must know, for example, what current changes are to be expected when a voltage, a resistance or a reactance is increased or decreased in value.

Complete failures of coils, condensers, resistors and circuit connections, as well as partial changes in the electrical values of these parts, are common everyday radio defects. Once you are familiar with the fundamental laws applying to radio circuits, you will be able to predict the effects which these failures will have upon circuits, and will therefore be able to locate defective parts very rapidly.

Briefly, then, the purpose of the next ten experiments (21 through 30) in your practical demonstration course is *to show you how Ohm's Law and Kirchhoff's Laws govern circuit behavior in radio equipment.* In these experiments, you will learn to use the N.R.I. Tester which you constructed after completing Experiment 20, and you will secure additional experience in reading schematic circuit diagrams.

Contents of Radio Kit 3RK-1

The parts included in your Radio Kit 3RK-1 are illustrated in Fig. *1*, and listed in the caption underneath. Check off on this list the parts which you receive, to be sure you have all of them. Do not destroy any of these parts until you have completed your entire N.R.I. course, for many of the parts will be used over and over again in later experiments.

IMPORTANT: If any part in your Radio Kit 3RK-1 is obviously defective or has been damaged during shipment, please return it to the Institute *immediately* for replacement.

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 21

Purpose: ***1.*** **To show that d.c. voltage sources add when connected in series aiding; 2. To show that d.c. voltage sources subtract when connected in series bucking; 3. To show that d.c. voltage sources which are equal in value remain unchanged when connected in parallel.**

✓ *Step 1. To learn how to read the DC scale,* study carefully the exact-size reproductions of this scale in Fig. *2*, where examples of readings for four different pointer positions are given. Observe that the scale reads from 0 to 4.5, with numerical values on the scale being read in much the same way as the values on scale I_M were read in previous experiments. When the pointer is directly on a numbered

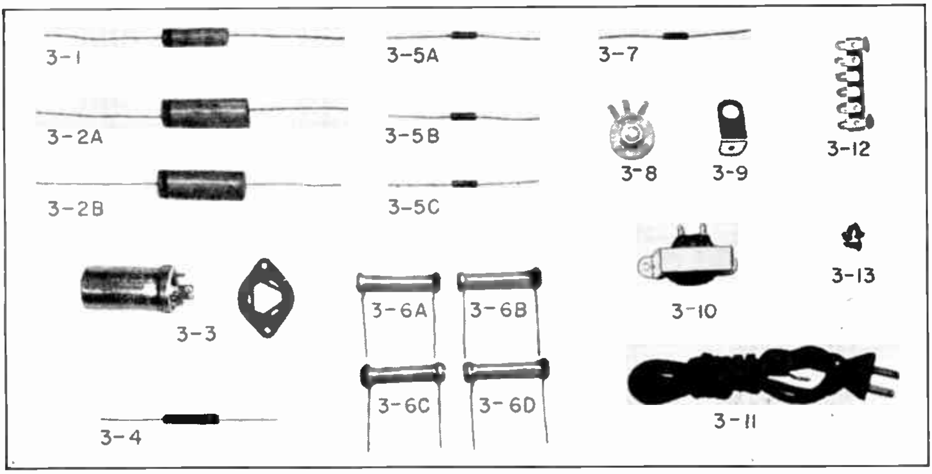

Fig. 1. The parts included in Radio Kit 3RK-1 are pictured above, and are identified in the list below. Some resistors may have a better tolerance (a lower percentage tolerance) than that indicated here.

Part No.	*Description*
3-1	One .05-mfd., 400-volt paper condenser.
3-2A	One .25-mfd., 400-volt paper condenser.
3-2B	One .25-mfd., 400-volt paper condenser. Same as Part *3-2A*.
3-3	One dual 10-10-mfd., 450 working volt electrolytic condenser.
3-3A	(At right of Part *3-3* in Fig. *1*). Bakelite mounting wafer for electrolytic condenser.
3-4	One 200-ohm, 1-watt resistor with 10% tolerance (color-coded red, black, brown and silver).
3-5A	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red and silver).
3-5B	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red and silver).
3-5C	One 1,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, black, red and silver). Parts *3-5A*, *3-5B* and *3-5C* are identical.
3-6A*	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange).
3-6B*	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange).
3-6C*	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange).
3-6D*	One 40,000-ohm, 3-watt resistor with 20% tolerance (color-coded yellow, black and orange). Parts *3-6A*, *3-6B*, *3-6C* and *3-6D* are identical.
3-7	One 1-megohm, ½-watt resistor with 10% tolerance (color-coded brown, black, green and silver).
3-8	One 1,000-ohm wire-wound potentiometer.
3-9	Mounting bracket for potentiometer.
3-10	One 10-henry choke coil with 25-ma. current rating.
3-11	One 5-foot power line cord with attached outlet plug. (Students who do not have power line facilities will use this cord for storage battery connections.)
3-12	One 6-lug terminal strip with four of the lugs insulated.
3-13	Three ⅜-inch No. 6 round-head wood screws.

* You may receive 39,000-ohm units for these resistors, depending on what we have in stock when we pack your kit. Go right ahead and use them as 40,000-ohm resistors. The difference won't have any noticeable effects in any of your experiments.

You should have the following parts left over from Radio Kits 1RK and 2RK.

1-1	One 55-watt electric soldering iron (or Part *1-1A*, a plain soldering iron).
1-2	One soldering iron holder.
1-3	Remainder of roll of rosin-core solder.
1-16	One 18,000-ohm, ½-watt resistor (color-coded brown, gray, orange and silver).
2-17	Remainder of roll of red push-back hook-up wire.
2-19A & 2-19B	Eight tinned copper strips, now mounted on the four 1.5-volt flashlight cells which you obtained yourself.
	Miscellaneous pieces of various types of hook-up wire, soldering lugs, and small amounts of plain solder.
	Assembled N.R.I. Tester with test leads.
	All tools which were specified in the previous experiments and which were to be obtained by you.

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
3	VOLTAGE OF CELL A	1,3	1.5
	VOLTAGE OF CELL B	1,5	1.5
	VOLTAGE OF CELL C	1,5	1.5
	VOLTAGE OF CELL D	1,5	1.5
4	VOLTAGE OF CELL A	1,5	1.5
	VOLTAGE OF CELLS A+B	3,0	3.0
	VOLTAGE OF CELLS A+B+C	4,5	4.5
	VOLTAGE OF CELLS A+B+C+D	6	6.0
5	VOLTAGE OF CELLS A+B+C−D	3	3.0
	VOLTAGE OF CELLS B+C−D	1,5	1.5
	VOLTAGE OF CELLS C−D	0	0
6	VOLTAGE OF CELLS A+B−C−D	0 ✓	0 ✓
	VOLTAGE OF CELLS A+B−C	1,2 ✓	1.5 ✓
	VOLTAGE OF CELLS B−C	0 ✓	0 ✓
	VOLTAGE OF CELLS B−C−D	1,5 ✓	1.5 ✓
8	CELLS A,B,C AND D IN PARALLEL	1,5	1.5
9	CELLS A,B,C AND D IN SERIES-PARALLEL	3,	3.0
10	CELLS A,B,C AND D IN SERIES-PARALLEL	3,	3.0

TABLE 21. Record your results here for Experiment 21. The check mark (✓) indicates that each of the readings obtained for Step 7 in the N.R.I. laboratory was the same as the corresponding reading for Step 6.

line, read the number above that line. When the pointer is on a short line between two numbered lines, read a value halfway between the values of the two adjacent numbered lines.

Step 2. Check the calibration of your N.R.I. Tester as instructed in the last section of Manual 2RK, and recalibrate if necessary. Be sure to remove both test leads from the jacks on the N.R.I. Tester panel during a check-up of calibration and during the recalibration procedure, and set the selector switch to *100×V* during calibration. Do not touch any terminals or leads behind the panel with your fingers during calibration, for body capacity, the resistance of the body (around 100,000 ohms), and hum voltage pick-up by the body can cause errors in calibration.

In the future, check the calibration of the N.R.I. Tester the first time you use the instrument each day. Additional checks can be made quickly at any time if you suspect an error in calibration.*

IMPORTANT: Overloading of the meter will appear to destroy the zero calibration of the N.R.I. Tester, but this is merely a temporary effect which will be corrected automatically if the next measurement you make will give nearly a full-scale reading. However, you can correct the calibration shift yourself by removing the calibrating clip from the —9C battery terminal, touching it momentarily to a terminal 4½ volts less negative

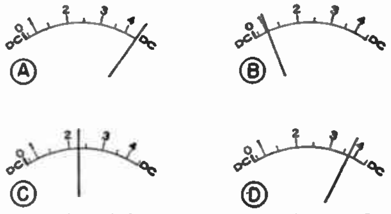

FIG. 2. Actual-size reproductions of the *DC* scale on the meter of the N.R.I. Tester, with examples showing how to read this scale at four different pointer positions. The readings are as follows: *A*—4.5; *B*—1.1; *C*—2.3; *D*—3.75.

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* If you write to N.R.I. regarding this tester, please refer to it as the *N.R.I Tester for Experiments.*

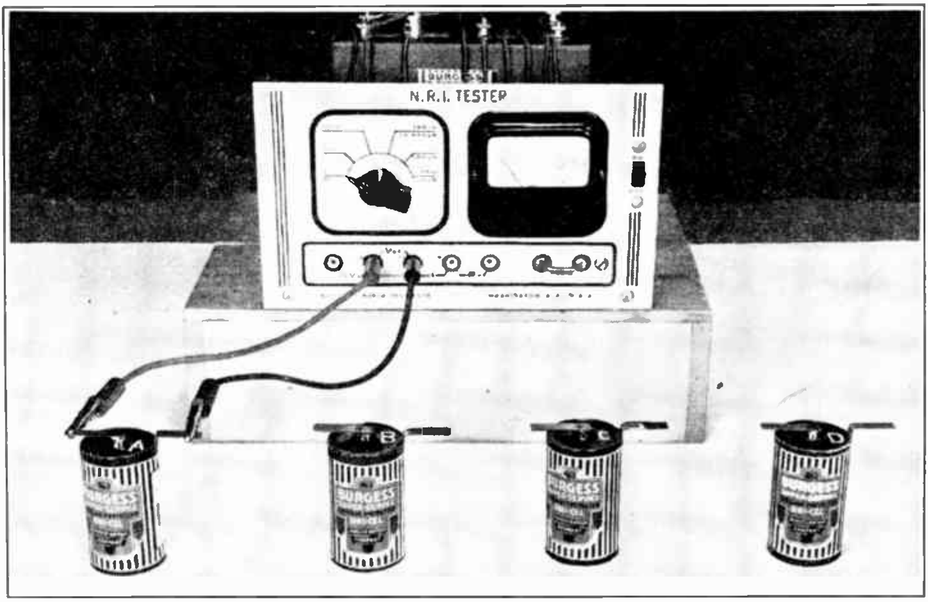

FIG. 3 Method of using the N.R.I. Tester to measure the voltage of individual dry cells. This set-up is used in Step 3 of Experiment 21. The test leads were shortened for this photograph in order to make them show more clearly, but *do not shorten your own test leads.* Placing the N.R.I. Tester on a box makes it easier to read the meter accurately.

(—4½C), then replacing the clip on its original terminal. This restores the iron vane in the meter to its normal non-magnetized state.

✓ *Step 3. Place before you the four flashlight cells* on which you have previously placed terminal strips. Place before you also the N.R.I. Tester, with its panel and meter facing you. Plug the red probe into the $+V_{DC}$ jack, plug the black probe into the $-V_{DC}$ jack, and set the selector switch to *V* as shown in Fig. *3*, so that your N.R.I. Tester will serve as a 0 to 4.5-volt d.c. voltmeter and will read values in volts directly on the *DC* scale.

With your metal-marking crayon, mark your four cells *A*, *B*, *C* and *D* respectively, as shown in Fig. *3*.

Place the red clip on the + (center) terminal of cell *A*, place the black clip on the — terminal of this cell, turn on the N. R. I. Tester, read the meter on the *DC* scale, and record your result in Table *21* as the voltage of cell *A* in volts. In the same manner, measure the voltage of each of the other cells, and record their values in Table *21*.

WARNING

Do not allow the alligator test clips to remain in contact with the panel or chassis of the N.R.I. Tester for any period of time, for this may short-circuit the C battery and drain it in a few minutes, even if the switch on the tester panel is *OFF*.

Get the habit of pulling out the test probes whenever you put the N.R.I. Tester away or leave it for any reason, to prevent the clips from touching the chassis accidentally.

✓ *Step 4. To measure the voltages of cells when connected in series-aiding,* connect your four cells together in series-aiding exactly as shown in Fig. *4*, so that the — terminal of cell *A* goes to the + terminal of cell *B*, the — terminal of *B* goes to the + of *C*, and the — of C goes to the + of D. Since the cell terminals were previously tinned, simply overlap the terminals which are to be connected together, then apply the heated soldering iron to the uppermost terminal. Rotate the selector switch one notch to the right, to setting $3 \times V$, without moving the probes. Your N. R. I. Tester is now serving as a 0 to 13.5-volt d.c. voltmeter, and you will have to multiply each reading on the *DC* scale by 3 to get the actual value of the voltage being measured.

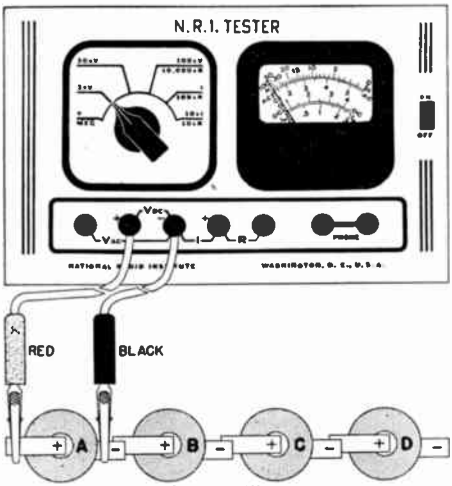

FIG. 4. This diagram illustrates how voltage measurements are made on a group of four flashlight cells connected in series-aiding for Step 4 of Experiment 21.

Place the red clip on the + terminal of cell A, place the black clip on the — terminal of cell A, read the meter on the *DC* scale, multiply the reading by 3, and record the result in Table *21* as the voltage of cell A. (For reasons explained in the discussion, do not expect this reading to check exactly with the first reading taken in Step 3.)

Move the black clip to the — terminal of cell B, leave the red clip on the + terminal of cell A, read the meter on the *DC* scale, multiply the reading by *3*, and record your result as the voltage of cells A + B.

Place the black clip on the — terminal of cell C, read the meter on the *DC* scale, multiply the reading by 3, and record your result in Table *21* as the voltage of cells $A + B + C$.

Move the black clip to the — terminal of cell D, read the meter on the *DC* scale, multiply the reading by 3, and record your result in Table *21* as the voltage of cells $A + B + C + D$.

Step 5. To measure voltages when four cells are connected together in series with three aiding and one bucking, as shown in Fig. *5*, first disconnect cell D from the group. Now turn cell D around so that its — terminal is in contact with the — terminal of cell C, and solder these two terminals together. Place the red clip on the + terminal of cell A, place the black clip on the + terminal of cell D, change the selector switch to setting V, read the meter on the *DC* scale, and record this reading in Table *21* as the voltage of cells $A + B + C - D$.

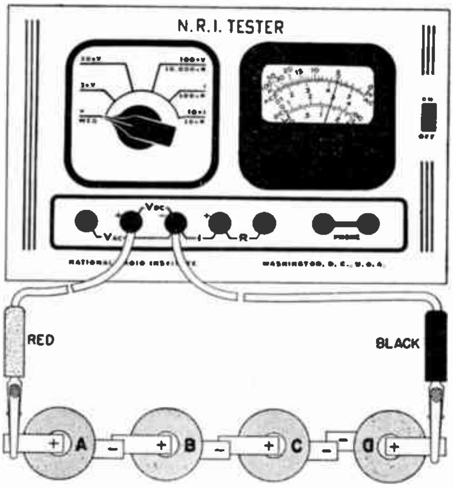

FIG. 5. Method of connecting four flashlight cells in series with three aiding and one bucking, with the *V* range of the N.R.I. Tester being used to check voltages. This measurement is made in Step 5 of Experiment 21.

Move the red clip to the — terminal of cell A, read the meter on the *DC* scale, and record your reading as the voltage of cells $B + C - D$.

Move the red clip to the — terminal of cell *B*, read the meter on the *DC* scale, and record your reading as the voltage of cells $C - D$.

Step 6. To make voltage measurements on four cells connected in series, with two cells aiding and two cells bucking, unsolder the terminals of cell *C* from the others in this group, turn this cell around so that its — terminal is on the — terminal of cell *B*, then solder the cell terminals into position again as shown in Fig. *6*. Place the red clip on the + terminal of *A*, place the black clip on the + terminal of *D*, read the meter on the *DC* scale, and record your reading as the voltage of cells $A + B - C - D$.

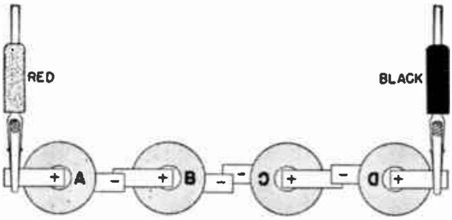

FIG. 6. Cell connections and test clip positions for Step 6 of Experiment 21.

Move the black clip to the + terminal of cell *C*, read the meter, and record your result in Table *21* as the voltage of cells $A + B - C$.

Now move the red clip to the + terminal of cell *B*, read the meter, and record your result as the voltage of cells $B - C$.

Move the black clip back to the + terminal of cell *D*. You will now get a zero or a downscale reading, indicating improper polarity of connections, so reverse the positions of the red and black clips; that is, place the black clip on the — terminal of cell *A*, and place the red clip on the + terminal of cell *D*. Read the meter and record your result in Table *21* as the voltage of cells $B - C - D$.

Step 7. Take a short length of red hook-up wire and connect the + terminal of cell B to the + terminal of cell C by means of temporary soldered lap joints. Take another length of hook-up wire and connect the + terminal of cell *A* to the + terminal of cell *D* by means of temporary soldered lap joints, as shown in Fig. 7. If you notice a spark when making either of these connections, check the polarity of battery connections against the diagram in Fig. 7. There should be no sparks if connections are made properly.

Now repeat each of the *measurements* called for in Step 6, to see if these two wire connections affect any of the voltage values. Make a small check mark after each of the readings for Step 6 in Table *21* which are still the same. Finally, remove the two wires and disconnect the four cells.

Step 8. To measure the voltage provided by four cells connected in parallel, first place the four flashlight cells side by side in the manner shown in Fig *8*. Cut a 6-inch length of hook-up wire and remove all insulation from it, then place this bare tinned copper wire over the + terminals of the four cells as shown in Fig. *8*, and solder the wire to each terminal. In the same manner, take another 6-inch length of bare tinned

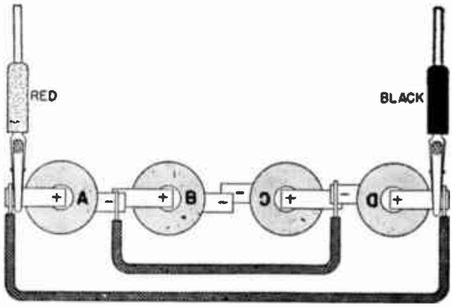

FIG. 7. Cell connections and test clip positions for Step 7 of Experiment 21.

copper wire and connect together the — terminals of the four cells. Place the red clip on any + terminal, place the black clip on any — terminal, and measure the voltage of these four cells in parallel with the *V* range of your N.R.I. Tester. Read the meter on the *DC* scale, and record your result in Table *21* as the voltage of four cells in parallel.

TOLERANCES OF RADIO PARTS

It is important to realize that any practical radio measurement will be affected by variations in the apparatus used in the circuit. When we calculate a value in mathematics, it is possible to obtain an answer that is so accurate it can be considered perfect. Measurements, on the other hand, depend upon the tolerances of parts, the characteristics of the measuring device and the ability to read scales closely.

Radio parts vary as much as 20% from the rated value in many cases, yet are considered satisfactory. (The standard tolerance is actually 20% in the case of resistors; thus, a resistor rated at 100 ohms may have any value from 80 ohms to 120 ohms.)

Therefore, do not expect to obtain exactly the calculated or N.R.I. values. You are using your own tester and parts, and the values of these parts can be quite different from the values of the parts used at N.R.I. without exceeding normal tolerances.

Obviously, there is little use in trying to make your readings extremely accurate, when radio parts are not exact in the first place. This is a practical fact, and you will find that the same condition exists in radio receivers and transmitters.

✓ *Step 9. To measure the voltage of parallel pairs of cells connected in series,* cut each of the bare wires in Fig. *8* at its mid-point, then move down the cell groups including *C* and *D,* and connect the + terminal of *C* to the — terminal of *B* by means of a lap joint, as shown in Fig. *9.* Place the black clip on the — terminal of cell *D,* place the red clip on the + terminal of cell *A,* read the meter on the *DC* scale, and record your result as the voltage of four cells connected in series-parallel according to Fig. *9.* Now disconnect these four cells.

✓ *Step 10. To measure the voltage of four cells connected together in series-parallel,* first connect cells *A* and *B* in series aiding, as shown in Fig. *10.* Next, connect cells *C* and *D* in series aiding also. Now connect these two series groups of cells in parallel in the manner shown in Fig. *10,* by using two 1½-inch lengths of bare tinned copper wire. (You can cut these lengths from the bare wire prepared for Steps 8 and 9.) Place the red clip on the + terminal of cell *A,* place the black clip on the — terminal of cell *B,* and read the meter on the *DC* scale. Record your result in Table *21* as the voltage of four cells connected in series-parallel.

Discussion: A dry cell delivers essentially 1.5 volts by itself when new. When the test leads of the N. R. I. Tester are plugged into the V_{DC} jacks, and the selector switch is set at position *V,* you can read the voltage of a dry cell directly in volts on the *DC* scale of the meter.

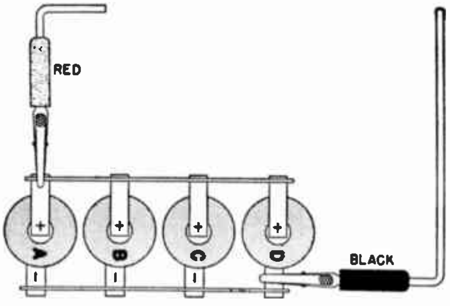

FIG. 8. Cell connections and test clip positions for Step 8 of Experiment 21.

There are four d.c. voltage ranges in all: *V*; *3×V*; *30×V*; *100×V*. In each case, you first read the meter on the *DC* scale, then multiply this reading by the factor indicated at the setting of the selector switch. Thus, when you place the selector switch at the *3×V* setting for one step in this experiment, you must read the meter on the *DC* scale, and multiply the value by 3 to get the actual voltage in volts.

This system for securing a number of different voltage ranges with only one meter is identical with that employed in the professional multimeters used by radio servicemen and radio engineers. After using an instrument a few times, these men find themselves able to multiply meter readings by the correct factors mentally and secure voltage values for the higher ranges almost as readily as when using a direct-reading range.

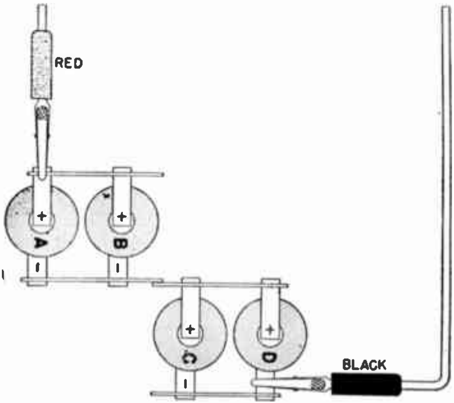

FIG. 9. Cell connections and test clip positions for Step 9 of Experiment 21, in which two parallel-connected pairs of dry cells are connected in series.

In the case of ranges which have multiplying factors of 10, 100, 1,000 or 10,000, it is a simple matter to add the indicated number of zeros to the meter reading. When the multiplying factor is 3 or 30, actual multiplication is required.

A good habit to form is that of turning the N. R. I. Tester on only while you are actually reading the meter. If you keep the power switch *OFF* during the preliminary set-ups and in between experiments, you will greatly increase the useful life of the batteries in the N. R. I. Tester.

In Step 3, you measure the voltage of each of the four flashlight cells with the N. R. I. Tester connected as a 0-4.5-volt d.c. voltmeter. Under this condition, your instrument has a sensitivity of 2,233,000 ohms-per-volt, which is exceptionally good for a d.c. voltmeter. If the four flashlight cells are new and all have the same dates stamped on them, they should all have essentially the same terminal voltages.

In Step 4, you use the *3×V* range for the first time, with your N. R. I. Tester serving as a 0-13.5-volt d.c. voltmeter under this condition. This means that you must multiply the reading on the *DC* scale by 3 to get the actual voltage each time. Naturally, you cannot read the voltage of a single cell as accurately with this range as you could with the *V* range, so do not expect your first reading to check too closely with the readings in Step 3.

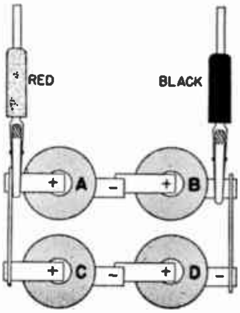

FIG. 10. Cell connections and test clip positions for Step 10 of Experiment 21, in which two series-connected pairs of dry cells are connected in parallel.

In Step 4, you connect the four cells in series-aiding, which means that unlike terminals of adjacent cells are connected together (— to +). Careful study of the voltage values which you obtained should indicate that the voltages of the individual cells add together when the cells are connected in series-aiding.

When connections to one of the cells are reversed as in Step 5, this cell is actually bucking the voltage of one of the other cells. Cells *C* and *D* in Fig. *5* can thus be considered to buck each other, so that there is essentially zero voltage between the positive terminals of these cells. As a result, voltage measurement across all four cells as shown in Fig. *5* should indicate the same voltage you obtained previously for cells *A* and *B* connected in series aiding. Likewise, when you connect the red clip to the + terminal of cell *B*, you should measure only the voltage of cell *B*. When the red clip is on the + terminal of cell *C*, the reading should be zero because these two cells buck each other.

When four cells are connected in series according to Step 6, so that cells *C* and *D* are connected with opposite polarity to that of cells *A* and *B*, we have the condition where one group of two series-connected cells is bucking the other group of two series-connected cells. As a result, the voltage across the group of four cells should be essentially zero for the measurement shown in Fig. *6*.

The additional measurements which you make in Step 6 should show you clearly how the voltages of cells in series add or subtract according to the polarity of their connections.

When an unequal number of cells are connected in a series-bucking arrangement, the polarity of the combination will be determined by the polarity of the greater voltage value. In other words, with three cells connected so that one bucks the other two, the polarity of the combination will be the polarity of the two cells which are identically connected. This holds true if the two identically connected cells are separated by the bucking third cell.

Step 7 illustrates clearly the fundamental fact that terminals which are at the same potential (zero voltage between them) can be connected together without affecting circuit conditions. You found in Step 6 that the + terminals of cells *A* and *D* were at zero potential with respect to each other, so in Step 7 you connect these two terminals together with a wire. You found also that the + terminals of cells *B* and *C* were alike in potential, so you connected these two together with another wire. It should be pointed out, however, that the + terminals of *B* and *C* are *not* at the same potential as the + terminals of *A* and *D*. In other words, a measurement between these two pairs of terminals would indicate a voltage, and this would be the voltage of cell *A*.

In your fundamental course, you learned that when identical voltage sources are connected together in parallel, the resultant voltage of the combination is the same as the voltage of an individual cell. In Step 8, you connect four identical cells in parallel and prove this fact for yourself. The voltage which you obtain for this step should be the same as the voltage for an individual cell.

Cells are connected in parallel when more current is required than can be supplied by a single cell. Four cells are capable of delivering four times as much current as one cell. This means that four cells in parallel will last essentially four times as long as one cell when used in a given circuit. Actually, the 1.5-volt A battery in your N.R.I. Tester contains four small cells connected in parallel.

When you divide the parallel group of four cells into two equal groups in Step 9, each group has a voltage of essentially 1.5 volts. When these groups are connected in series-aiding, you should obtain a voltage equal to that of two cells. With this series-parallel combination, you have a 3-volt battery which is capable of delivering twice the amount of current obtainable from two cells in series.

In Step 10, you set up another type of series-parallel circuit, and find that this gives exactly the same voltage as the circuit of Fig. *9*. Actually, these two series-parallel circuits have exactly the same characteristics, and would be identically the same electrically if the — terminals of cells *A* and *C* are connected together. These terminals are at the same potential, and hence the connection will not affect circuit conditions. Series-parallel circuits are used when both higher current and higher voltage are required than can be supplied by a single cell.

Practical Extra Information. Although the various steps in this experiment are relatively simple and easy to perform, they are of great practical importance. Dry cells connected in series, in parallel, and in various series-parallel combinations are used extensively in radio work.

The dry batteries used for portable radio receivers are a typical example; all of the voltages required for these sets are obtained from combinations of standard 1.5-volt dry cells. The plate circuits of these receivers require high voltages but low currents, and these are provided by large numbers of small 1.5-volt cells connected in series. The grid circuits have even lower current and voltage demands, and consequently the C batteries are also made up of small cells in series. The filament battery, on the other hand, must supply a low voltage but fairly high current, and usually you will find four dry cells connected in parallel for this purpose. A standard 45-volt B battery is made up of thirty 1.5-volt dry cells connected in series.

Dry cells are seldom connected in series-bucking in commercial radio equipment, but this connection is often utilized for experimental work. For example, if you required a voltage of 39 volts but had only a 45-volt B battery and four flashlight cells available, you could connect the four flashlight cells in series to give 6 volts, then connect this 6-volt battery in series-bucking with the 45-volt battery, so that the resulting voltage would be 45 — 6, or 39 volts.

Although we used dry cells as d.c. voltage sources in this experiment, the various rules and laws which were demonstrated will apply also to other d.c. voltage sources, such as d.c. generators.

Instructions for Report Statement No. 21. In the discussion of Step 9, it was pointed out that the series-parallel circuit shown in Fig. *10* had exactly the same characteristics as the series-parallel circuit of Fig. *9*; furthermore, you learned that these two circuits could be made the same *electrically* by connecting the minus terminals of Cells *A* and *C* together. (Any two points in a circuit can be connected together without affecting circuit conditions if the potential difference between those two points is zero.)

For this report statement, you are asked to prove that the — terminals of cells *A* and *C* in Fig. *10* are at the same potential. Do this by connecting the cells as shown in Fig. *10*, then place the red clip on the — terminal of cell *A*, and place the black clip on the — terminal of cell *C*. Measure the voltage between these points with the *V* range of the N. R. I. Tester, turn to the last page and make a check mark in Report Statement No. 21 after the voltage value which you obtained.

EXPERIMENT 22

***Purpose:* To demonstrate that Kirchhoff's Voltage Law holds true in a simple d.c. circuit.**

Step 1. Set up a simple series circuit consisting of four 1.5-volt dry cells and three 1,000-ohm resistors, as shown in Fig. *11A*.

The actual arrangement of these parts can be as shown in Fig. *11B*, in which the four flashlight cells are connected in series aiding. Connect resistor R_1 to the — terminal of cell *D* by means of a soldered lap joint. Connect resistors R_1, R_2 and R_3 together by means of temporary soldered hook joints.

Connect the right-hand terminal of R_3 to the + terminal of cell *A* with a suitable length of red hook-up wire, using a lap joint on the cell terminal and a soldered hook joint on the resistor lead. Set the N. R. I. Tester to measure d.c. voltages on the *V* range (set the selector switch to *V*, plug the red probe into the $+V_{DC}$ jack, and plug the black probe into the $-V_{DC}$ jack).

To prove Kirchhoff's Voltage Law, you will now measure the voltage across each part in this simple d.c. circuit, by starting with cell *A* and moving from part to part in the direction of electron flow. (Since electrons flow out of the — terminal of a voltage source, they will flow from the — terminal of *A* to the + terminal of *B* and continue in this direction through the circuit, as indicated by the arrows in the schematic diagram of Fig. *11A*.)

To prove Kirchhoff's Voltage Law, we must arbitrarily assume that a voltage having a given polarity (direction) in the circuit under consideration is a + value, and that a voltage having the opposite polarity is a — value. For the circuit of Fig. *11A*, we will assume that voltages having the same polarity as the dry cells are + values.

Place the red clip on the + terminal of cell *A*, and place the black clip on the — terminal of cell *A*, as shown in Fig. *11B*. Read the meter on the *DC* scale and record the value in Table *22* as the voltage of cell *A*. Place a + sign ahead of this value.

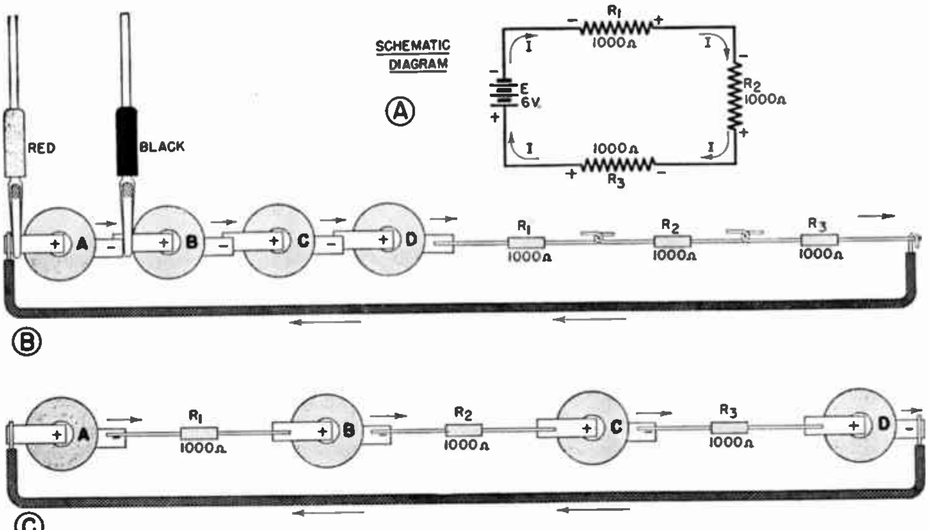

FIG. 11. Semi-pictorial and schematic circuit diagrams for Experiment 22. Arrows indicate the direction of electron flow in each case.

Now remove both clips at once, and move the clips to the terminals of the next part (cell *B*) without changing their relative positions. If an up-scale reading is secured, record it as a + value; if the meter reads backward, reverse the positions of the clips and record the reading as a — value. Remember that all other readings obtained with this reversed position of the clips must be recorded as negative values.

Here is another guide for determining the sign of a measured value in this circuit. Use a + sign when the black clip is ahead as you move in the direction of electron flow, and use a — sign when the red clip is ahead.

Move the red and black clips together around the circuit in the direction of electron flow until you have measured the voltage across each part and recorded it in Table *22*. Now, add together the + values first, then add together all the — values. The total of + values should be essentially equal to the total of — values if Kirchhoff's Voltage Law holds true for this d.c. circuit (they will seldom be exactly equal because all readings taken with meters are subject to normal variations).

Step 2. To show that Kirchhoff's Voltage Law holds true regardless of the positions of the resistors and cells in a simple d.c. circuit, rearrange your resistors and cells in the manner shown in Fig. *11C*. Following the same procedure outlined in Step 1, measure the voltage across each part in the circuit and record its value in the spaces provided for this purpose in Table *22*. When you have done this, break the circuit by unsoldering the red wire from the — terminal of cell *D*.

Add your measured values as described in Step 1 to check the accuracy of Kirchhoff's Voltage Law. Remember that natural inaccuracies in measuring and reading make an exact check almost impossible.

Dry cells are supplying energy whenever connected into a complete circuit. Therefore, if you stop making measurements for study purposes or any other reason while working with batteries, always break the circuit by unsoldering a lead from one cell terminal. You can easily reconnect this lead when you are ready to begin measurements again.

Discussion: In this experiment, you learned for yourself the exact nature of a voltage drop across a resistor. You know that the same current is flowing through all parts of your simple series circuit when it is completed. This flow of electrons through a resistor develops across the resistor a voltage, with the value of the voltage being determined by Ohm's Law (voltage = current × resistance).

Because your N. R. I. Tester is a

STEP 1			STEP 2		
PART BEING MEASURED	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS	PART BEING MEASURED	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
A	+1.5	+1.5	A	+1.	+1.5
B	+1.5	+1.5	R_1	-1.8	-2.0
C	+1.5	+1.5	B	+1.5	+1.5
D	+1.5	+1.5	R_2	-1.8	-2.0
R_1	-1.6	-2.0	C	+1.5	+1.5
R_2	1.7	-2.0	R_3	-1.6	-2.1
R_3	1.7	-2.1	D	+1.5	+1.5

TABLE 22. **Record your results here for Experiment 22.**

polarity-indicating device when connected as a d.c. voltmeter, you are able to determine the polarity of each voltage measured in this series circuit. In other words, whenever you secure an up-scale reading on the voltmeter, you know that the red clip of your meter is connected to the + terminal of the part whose voltage you are measuring.

One thing you should realize from this experiment is that a voltage drop produced across a part by the flow of current through it always has opposite polarity to that of the voltage source which is forcing that current through the circuit.

In Step 1, you find that each dry cell provides essentially 1.5 volts, with all four dry cells having the same polarity. This means that you have a voltage source of 6 volts in your circuit. Measurement of the individual voltages across the resistors shows a voltage of essentially 2 volts across each resistor. The resistors all have the same polarity, and this is opposite to the polarity of the dry cells. The three resistors thus have a combined voltage drop of essentially 6 volts, which is equal to the combined voltage of your source. If your results agree fairly closely with these values, you have proved the accuracy of Kirchhoff's Voltage Law for a d.c. circuit.

This experiment also allows you to determine for yourself the direction in which electrons flow through a resistor. You know the direction in which electrons flow in this complete circuit, for you learned in your fundamental course that electrons always come out the — terminal of a voltage source, and flow through the source. Since you know the direction circuit toward the + terminal of the of electron flow in your circuit and since you know the polarity of each voltage drop through your measurements (this polarity is as indicated in the schematic diagram in Fig. *11A*), you arrive at the basic radio fact that *the resistor terminal at which electrons enter is negative*, and *the resistor terminal which electrons leave is positive*.

Thus, if you know the polarity of the voltage drop across a resistor, you can immediately specify the direction in which electrons are flowing through that resistor. Conversely, if you know the direction in which electrons are flowing through a resistor, you can specify the polarity of the voltage drop developed across that resistor.

Resistor values of 1,000 ohms were chosen for this experiment because this particular value allows you to determine the current flowing through the resistor without going to the trouble of making a current measurement. It so happens that the current value in milliamperes flowing through a 1,000-ohm resistor is exactly equal to the voltage in volts across that resistor. This means that if you measure a voltage drop of 2 volts across 1,000-ohm resistor R_1, you have a current of 2 ma. flowing through that resistor. This relationship beteen current and voltage holds true only for a 1,000-ohm resistor, as you can readily verify by means of Ohm's Law.*

Step 2 verifies Kirchhoff's Voltage Law in much the same manner as does Step 1, and also demonstrates in a convincing manner the basic fact that in a series circuit, the current through the circuit and the voltage across individual parts in the circuit remain

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*$E = I \times R$; when R is in ohms and E is in volts, I is in amperes in this equation. Dividing current in milliamperes by 1,000 gives current in amperes, so we can say that $E = \frac{I_{ma}}{1{,}000} \times R$; since R is 1,000, the formula becomes $E = \frac{I_{ma}}{1{,}000} \times 1{,}000$. Cancelling now gives $E = I_{ma}$.

exactly the same regardless of the positions of the parts in the circuit.

Once you understand clearly the simple basic facts presented in this experiment, and realize that Kirchhoff's Voltage Law must hold true for any simple d.c. series circuit, you will have taken a tremendous step toward complete mastery of fundamental radio principles.

Instructions for Report Statement No. 22. You learned in this experiment and in your regular course that the sum of the voltage sources acting in any given circuit must equal the sum of the voltage drops in that circuit, according to Kirchhoff's Voltage Law. Under this condition, the voltage which you would measure between any two points in a circuit would be the difference between the voltage source values and the voltage drop values existing between these two points. For this report statement, you will make a measurement which proves the preceding statement.

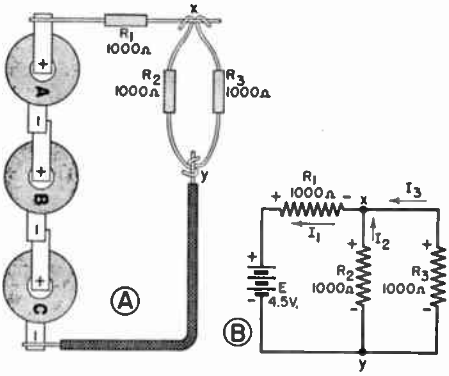

FIG. 12. Semi-pictorial and schematic circuit diagrams for Experiment 23.

Reconnect the red lead to the — terminal of Cell *D* in Fig. *11C*, then use your N. R. I. Tester to measure the voltage between the + terminal of cell *A* and the — terminal of cell *B*. To make this measurement, place the red clip of the N. R. I. Tester on the + terminal of cell *A*, and place the black clip on the — terminal of cell *B*. After measuring the voltage between these two points, turn to the last page and place a check mark after the voltage value which is closest to that which you measured.

Finally, turn off the N. R. I. Tester, then disconnect your circuit (Fig. *11C*) completely by unsoldering the resistors and the length of red hook-up wire.

EXPERIMENT 23

***Purpose:* To demonstrate that Kirchhoff's Voltage and Current Laws hold true for a complex d.c. circuit having a single voltage source.**

Step 1. After checking the calibration of your N. R. I. Tester (this is necessary only if this is the first experiment you are doing today), *set up the complex d.c. circuit shown in Figs. 12A and 12B,* by first connecting flashlight cells *A*, *B* and *C* in series aiding.

Connect one lead of resistor R_1 to the + terminal of cell *A* by means of a soldered lap joint. Connect a length of red hook-up wire to the — terminal of cell *C* with a soldered lap joint. Bend a hook in each end of the other two 1,000-ohm resistors (R_2 and R_3), then connect these two resistors in parallel between the free end of the hook-up wire and the free lead of R_1 with temporary soldered hook joints, as shown in Fig *12A.*

To prove that Kirchhoff's Voltage Law holds true for the closed circuit consisting of voltage source *E*, resistor R_1 and resistor R_2 in Fig. *12B,* use the N. R. I. Tester as a 0-4.5-volt d.c. voltmeter (the *V* range) to measure the voltage across each part of this closed circuit. Do this by measuring the source voltage first; place the red clip on the + terminal of *A*, place the black clip on the — terminal of *C*, read the meter, and record your result in Table *23*.

Now move your two test clips together around this circuit in the direction of electron flow. This means that you will next measure the voltage across R_2, by placing the black clip on its upper lead (at point x), and placing the red clip on its lower lead. Naturally, this makes the meter read down-scale since the voltage across R_2 is a voltage drop; therefore, reverse the positions of the test clips, read the meter, and record your result with a — sign ahead of it in the proper space in Table *23*.

Measure the voltage drop across R_1 and record its value in Table *23*.

Finally, measure the voltage drop across resistor R_3 and record its value in Table *23*, then unsolder joint y (Fig. *12A*) so as to prepare for the next experiment and at the same time open the circuit.

Since the voltage value measured across a 1,000-ohm resistor corresponds to the current value in ma. through the resistor, you will not have to record current values separately.

Discussion: The measurements which you make in this experiment will verify both of Kirchhoff's Laws for d.c. circuits. Let us first consider the voltage law.

The 4.5-volt voltage source, resistor R_1 and resistor R_2 form one complete circuit. If the measured value of the source voltage is essentially equal to the sum of the voltage drops across R_1 and R_2, you have confirmed Kirchhoff's Voltage Law for this circuit.

The other complete circuit around which Kirchhoff's Law should hold true is that consisting of E, R_3 and R_1. Add together arithmetically the values which you obtained for these resistors; if they add up to the source voltage, you have performed the experiment correctly.

Kirchhoff's Current Law says that the currents flowing to a given point in a circuit must be equal to the currents flowing away from that point. In other words, currents I_2 and I_3 in Fig. *12B* should add up to the value of current I_1. (The arrows on this diagram indicate the direction of electron flow; current flow is considered to be in the opposite direction. Either electron flow or current flow can be employed, provided you use the same one all through a series of calculations.)

NATURE OF MEASUREMENT	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
VOLTAGE ACROSS SOURCE	+4.5	+4.5
VOLTAGE ACROSS R_2 (SAME AS I_2 IN MA.)	-1.5	-1.5
VOLTAGE ACROSS R_1 (SAME AS I_1 IN MA.)	-3	-3.0
VOLTAGE ACROSS R_3 (SAME AS I_3 IN MA.)	-1.5	-1.5

TABLE 23. **Record your results here for Experiment 23.**

If the value which you obtained by adding currents I_2 and I_3 is essentially equal to current I_1, you have verified Kirchhoff's Current Law. Thus, adding N. R. I. values of 1.5 and 1.5 for I_2 and I_3 gives 3.0 ma., which is the same as the recorded N. R. I. value of 3.0 for I_1.

Note that the same voltage drops were measured across R_2 and R_3; this proves conclusively that parts connected in parallel all have the same voltage across them.

Instructions for Report Statement No. 23. Radio men sometimes find it necessary to measure the voltage of a source having terminals which cannot be reached conveniently without disconnecting a lot of apparatus. Sometimes it is a physical impossibility to measure the source voltage at its source; measurement of the induced voltage in a transformer is one example. In a situation like this, the practical radio man will break the circuit at some point and measure the voltage between the terminals thus provided. The voltage measured in this manner will be essentially equal to the source voltage if the voltmeter resistance is many times higher than any resistance in the circuit under consideration, and this condition is almost always true when using a vacuum tube voltmeter such as the N. R. I. Tester.

For this experiment, you will duplicate a practical voltage measurement like this by placing the black clip of the N. R. I. Tester on the red lead which you unsoldered from joint *y* in Fig. *12*, placing the red clip on either one or both of the resistor leads which formerly went to joint *y*, and measuring the voltage with the *V* range of the N. R. I. Tester. After doing this, turn to the last page and make a check mark after the voltage value which is closest to that which you measured.

EXPERIMENT 24

Purpose: **To demonstrate that Kirchhoff's Voltage and Current Laws hold true in a circuit which has more than one source of e.m.f.**

Step 1. Starting with the circuit of Fig. 12A, insert 1.5-volt dry cell D in series with resistor R_3 in such a manner that your set-up now appears as shown in Fig. *13A*. The schematic circuit will now have the form shown in Fig. *13B*, with the + terminal of E_1 (dry cell *D*) going to one lead of R_3, and with the — terminal of this cell going to the — terminal of cell *C*.

Considering first the closed circuit consisting of *E*, R_1 and R_2, move completely around this circuit with your 0-4.5-volt d.c. voltmeter and measure the voltage across each part. Remember that when recording the voltage values in Table *24*, you are to place a + sign ahead of any value having the same polarity as battery *E*, and a — sign whenever a voltage has the opposite polarity. The set-up for measuring the voltage across R_1 is shown in Fig. *13C*.

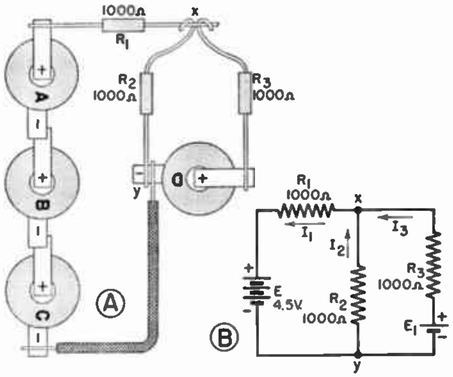

FIG. 13. Semi-pictorial and schematic circuit diagrams for Experiment 24.

Considering next the closed circuit consisting of *E*, E_1, R_3 and R_1, measure the voltage across each part in the same manner, and record in Table *24* the voltages measured for E_1 and R_3. You will find that the voltage across E_1 is opposite in polarity to that of *E*, and you will therefore have to place a — sign ahead of the measured value for E_1. You do not have to record the voltages for *E* and R_1 again, since you have already measured these.

Step 2. To check Kirchhoff's Voltage Law for the closed circuit consisting of E_1, R_3 and R_2, measure the voltage across each part while moving in the same direction around the circuit, giving a + sign to voltages having the polarity of E_1. Record your measured values on the last three lines in Table *24*.

Now unsolder the two leads from the — terminal of cell *D* (Fig. *13A*) and separate these leads, so as to prevent the dry cells from discharging.

Discussion: In each of the three complete circuits in which you made measurements for Steps 1 and 2, the source voltage (the sum of the source voltages in circuit E - E_1 - R_3 - R_1) should be approximately equal to the voltage drops when + and — signs are taken into account, for Kirchhoff's Voltage Laws hold true.

Thus, in circuit E - R_1 - R_2, the N. R. I. source value of +4.5 is equal to the sum of —2.5 and —2.0.

In circuit E-R_1-R_3-E_1, the source voltages of +4.5 and —1.5 buck each other, leaving a source voltage of 3 volts in this circuit, which is equal to the sum of the —2.5 and —.5 volt voltage drops.

In circuit E_1-R_3-R_2, the source voltage of +1.5 volts is equal to the algebraic sum (the numerical difference) of +.5 and —2.0, which is —1.5 volts. These values indicate that resistor R_2 is actually transferring into circuit E_1-R_3-R_2 a portion of the larger voltage source E, and cell E_1 is bucking out part of this voltage available across R_2. The difference, or .5 volts, appears across and sends current through R_3.

Before you can apply Kirchhoff's Current Law, you must determine the direction of electron flow through each resistor. You can do this very easily if you mark the polarity of each resistor on the schematic circuit diagram in Fig. *13B*. Do this as you make each voltage measurement. The direction of electron flow will then be from — to + through each resistor. You should find that the directions are as indicated by the arrows in Fig. *13B*. This means that currents I_2 *and* I_3 are flowing toward point x, and current I_1 is flowing away from this point. If the sum of I_2 and I_3 is essentially equal to I_1, you know that currents flowing to this point are equal to currents flowing away from the point, and you have proved Kirchhoff's Current Law.

Since 1000-ohm resistors are used, the current in ma. through a resistor will be the same as the voltage in volts across that resistor. Adding the N. R. I. values of 2.0 and .5 for I_2 and I_3 gives 2.5 ma., which is equal to the N. R. I. value of 2.5 ma. for I_1, thus verifying Kirchhoff's Current Law.

STEP	NATURE OF MEASUREMENT	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
1	VOLTAGE ACROSS E	+4.5	+4.5
	VOLTAGE ACROSS R_1 (SAME AS I_1 IN MA.)	-2.5	-2.5
	VOLTAGE ACROSS R_2 (SAME AS I_2 IN MA.)	-2.0	-2.0
	VOLTAGE ACROSS R_3 (SAME AS I_3 IN MA.)	-.5	-.5
	VOLTAGE ACROSS E_1	-1.5	-1.5
2	VOLTAGE ACROSS E_1	+1.5	+1.5
	VOLTAGE ACROSS R_3	+.5	+.5
	VOLTAGE ACROSS R_2	-2.0	-2.0

TABLE 24. Record your results here for Experiment 24.

Practical Extra Information. The voltage drop produced by the flow of current through a resistor is widely used in radio. Perhaps the most common example is that of the cathode resistor in a vacuum tube circuit; the flow of plate-cathode current through this resistor develops across the resistor a voltage drop which is usually made to serve as the C bias voltage for the tube. Voltage drops across resistors are also used for automatic volume control purposes, for frequency-correcting purposes, for preventing undesirable oscillation, for protection against overloads, and for many similar purposes which will be studied in detail in the experiments which follow and in your regular course.

A voltage drop across a resistor is sometimes considered as a secondary source of voltage when used in many of the applications just mentioned. Actually, the resistor in question is not a true voltage source, but is merely transferring a true source voltage (produced by a dry cell or power pack) from one circuit to another.

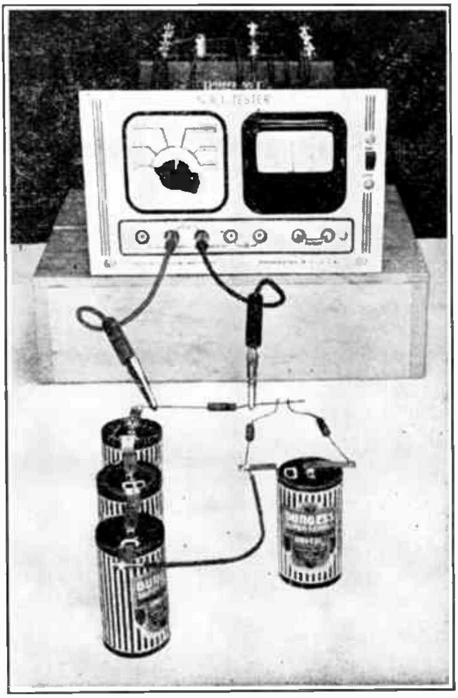

FIG. 13C. This photographic illustration shows the parts connected for Step 1 of Experiment 24, with the N.R.I. Tester connected to measure the voltage across R_1.

Instructions for Report Statement No. 24. If you reverse the polarity of either of the voltage sources employed in the circuit of Fig. *13*, circuit conditions will change.

For Report Statement No. 24, you will prove this by reversing the connections of cell *D* in Fig. *13* in the following manner: Unsolder the lead of R_3 from the + terminal of cell *D*. Turn the cell around, and solder the free lead of R_3 to the — terminal of this cell. Solder the red wire and the free lead of R_2 to the + terminal of cell *D*. You should now have the circuit of Fig. *13A* with the terminals of cell *D* reversed. After doing this, measure the voltage across R_3 with the N. R. I. Tester, and compare your measured value with that obtained across R_3 in Step 1. (When comparing these voltages, consider only the voltage values, without regard for + and — signs.) Now turn to the last page and check the answer which describes your result.

EXPERIMENT 25

***Purpose:* To demonstrate that a definite period of time is required to charge or discharge a condenser through a resistance.**

Step 1. To charge a .5-mfd. capacity through a 10-megohm resistance, first connect the two .25-mfd. tubular paper condensers (Parts *3-2A* and *3-2B*) in parallel to secure a combined capacity of .5 mfd., using temporary soldered connections as shown in Fig. *14*. Touch the leads of the two parallel-connected condensers together to discharge the condensers. Now bend the condenser leads so they can be inserted in the two *R* jacks on the N. R. I. Tester panel. Set the selector switch at *V*, turn on the N. R. I. Tester, and insert the .5-mfd. capacity into the *R* jacks while watching the meter. The schematic circuit for this set-up appears in Fig. *16A*. The pointer should rise rapidly to 4.5 volts, then return gradually to nearly 0; estimate the length of time it takes for the pointer to return from 4.5 to 1.5 on the *DC* scale, and record the value in Table *25*, but leave the condensers in the jacks for about two minutes, until the pointer comes to rest near zero.

You can estimate the time in seconds simply by counting at a normal speaking rate as follows: One hundred and one, one hundred and two, one hundred and three, etc. Each phrase will then be approximately equal to one second. If you practice counting first while watching the second hand of your watch or clock, you can do this very accurately.

STEP	NATURE OF MEASUREMENT	YOUR TIME IN SECONDS	N.R.I. TIME IN SECONDS	COMPUTED TIME CONSTANT IN SEC.
1	CHARGING .5 MFD. WITH 4.5 V. THRU 10 MEG.	7	6	5.
2	DISCHARGING .5 MFD. THRU 10 MEG.	6	6	5
3	DISCHARGING .5 MFD. THRU .9 MEG.	1 sec	less than 1 SEC.	.45

TABLE 25. Record your results here for Experiment 25.

Do not touch the condenser leads while making this measurement; grasp the paper sleeves of the condensers with your fingers to hold them into the jacks, for otherwise the resistance of your body will give confusing readings.

Step 2. To observe how the voltage varies across a .5-mfd. capacity while it is being charged directly by a 4.5-volt d.c. source, touch the leads of the two parallel-connected .25-mfd. condensers together to discharge the condensers, then insert the leads in the V_{DC} jacks on the N. R. I. Tester panel. Attach the alligator clip of the red test lead to the condenser lead which is in the + V_{DC} jack, and attach the black alligator clip to the condenser lead which is in the $-V_{DC}$ jack. Turn on the N. R. I. Tester, leaving the selector switch at *V*.

Using three of the flashlight cells connected in series aiding as the 4.5-volt d.c. source, hold the red probe on the + terminal of the cell group with one hand, and hold the black probe on the — terminal of the cell group, as shown in Fig. *15*, so as to secure the circuit shown in Fig. *16B*. When the meter pointer has come to rest at about 4.5 on the *DC* scale, remove the probes from the battery terminals, estimate the time required for the meter pointer to drop down to 1.5 on the *DC* scale, record your value in Table *25*, and turn off the Tester.

If you wish to repeat this experiment for any reason, discharge the condensers by shorting their leads with a screwdriver before starting the experiment again.

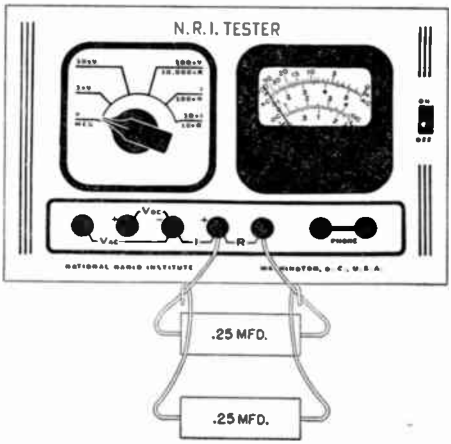

FIG. 14. Method of charging a .5-mfd. capacity for Step 1 of Experiment 25. (Two .25-mfd. condensers in parallel have a combined capacity of .5 mfd.)

Step 3. Connect the 1-megohm resistor (Part *3-7*) *in parallel with the .5-mfd. capacity as indicated in Fig. 16C, by using temporary soldered hook or lap joints,* and repeat the entire procedure set forth in Step 2. Again try to estimate the time re-

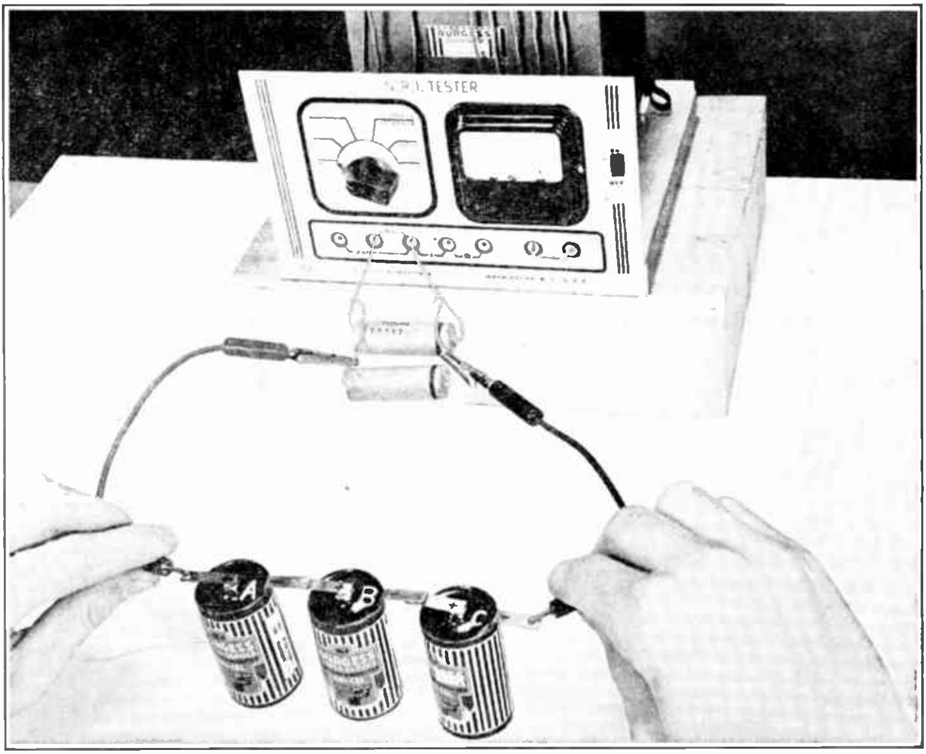

FIG. 15. Photographic illustration showing how apparatus is set up for Step 2 of Experiment 25.

quired for the pointer to drop from 4.5 to 1.5; if the pointer drops too fast for you to estimate the time, simply record in Table *25* the fact that the time was less than one second.

Now remove the test leads, remove the condenser-resistor combination from the V_{DC} jacks, and separate the condensers and resistor by unsoldering.

Discussion: When the .5-mfd. capacity is connected to the *R* jacks, the schematic circuit diagram for the set-up is as shown in Fig. *16A,* in which a 4.5-volt d.c. source (a portion of the battery system of the N. R. I. Tester) is charging the condenser through a 10-megohm resistor in the N. R. I. Tester. The meter and the vacuum tube in the N. R. I. Tester together measure the voltage developed across the 10-megohm resistor by the condenser charging current. When voltage is first applied to the condenser, the meter immediately swings to 4.5 on the *DC* scale, and therefore indictates the full voltage of the 4.5-volt d.c. source.

After reaching 4.5, the meter pointer immediately begins moving

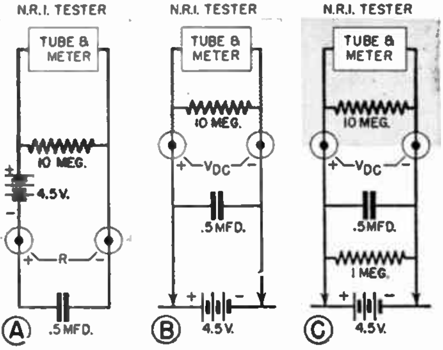

FIG 16. Schematic circuit diagrams for Experiment 25.

down scale, rather rapidly at first and then more slowly. The pointer drops in this manner because the condenser acquires a back e.m.f. (a voltage drop) as it charges. As the voltage drop increases across the condenser, the voltage drop across the resistor reduces correspondingly because the source voltage of 4.5 volts must divide itself between these two parts according to Kirchhoff's Voltage Law.

It is a fundamental radio fact that the rate at which a condenser charges depends only upon the value of the condenser and upon the value of the resistor through which the charging current flows. Furthermore, multiplying the resistance value in megohms by the capacity value in microfarads gives a time value in seconds which is known as the *time constant* of the condenser-resistance combination. During charging of a condenser, this time constant will be the time in seconds required for the condenser to charge up to 63% of its final voltage.

In our case, 63% of 4.5 volts is 2.85 volts. Subtracting this value of 2.85 volts from the total available voltage of 4.5 volts leaves 1.65 volts as the voltage across the 10-megohm resistor at the end of the time constant period. Estimating the time it takes for the voltage across the 10-megohm resistor to drop to 1.5 volts is close enough.

According to theory, the time constant for a .5-mfd. condenser and a 10-megohm resistor is 10 x .5, or 5 seconds. The time which you estimate and record in Table *25* should therefore be about five seconds.

After the pointer passes below 1.5, it will still take several minutes before it comes to rest. The pointer will not drop entirely to zero, for the condenser has a leakage resistance value (somewhere around 100 megohms) which may allow some current to flow through the circuit even when the condenser is fully charged. Tap the meter housing lightly to overcome bearing friction when the pointer is near zero.

In Step 2, you use an external d.c. voltage source of 4.5 volts and connect it directly to the condenser, with the N. R. I. Tester connected across the condenser leads to measure the condenser voltage, as shown in the schematic diagram in Fig. *16C*. When you hold the probes across the 4.5-volt d.c. source, this voltage is applied to the condenser in parallel with the 10-megohm resistance of the N. R. I. Tester. The meter therefore indicates the full d.c. source voltage of 4.5 volts for as long as you hold the probes on the batteries. After the condenser was fully charged, you removed the probes from the battery terminals. This allowed the condenser to discharge through the 10-megohm input resistance of the N. R. I. Tester.

In the case of discharge, the time constant is the time in seconds required for the condenser to discharge until its voltage is 37% of its original charged voltage. In other words, when the condenser voltage drops to .37 x 4.5, or to 1.65 volts, the end of the time constant period is reached.

In Step 2, you are actually measuring the voltage across the condenser, because the meter, the 10-megohm resistor and the condenser are all in parallel. Theoretically, therefore, it will take the time constant value of about five seconds for the condenser to discharge from 4.5 volts to 1.5 volts in Step 2. If your estimate is within a few seconds of this value, you can consider that you have performed this experiment satisfactorily.

Shunting the 1-megohm resistor across the .5-mfd. condenser lowers the 10-megohm N. R. I. Tester input resistance to about .9 megohm, since these two resistors are now in parallel.

This means that the condenser will discharge through .9 megohm when the external voltage source is removed. The time constant for .9 megohm and .5 mfd. is about .45 second; this means that the condenser voltage will drop to 1.5 volts in about half a second after the voltage source is removed. As you observed, this short time is very hard to estimate accurately; it is sufficient simply to say the time was less than one second.

Practical Extra Information. The basic radio fact which you have just observed, wherein a condenser employed in series with a resistor in a d.c. circuit requires a certain amount of time to charge and to discharge, has many practical applications in modern radio receiver circuits. Perhaps the best known of these applications is the automatic volume control circuit, which you take up in your regular lessons; here, the time delay characteristics of the resistor and condenser control the speed with which the a.v.c. system responds to changes in signal strength. Fast a.v.c. action is desirable in order to keep the volume essentially constant during periods when stations are fading in and out rapidly and during tuning from one station to another, but a.v.c. action must not be so fast that it responds to audio variations. The time constant employed must be a compromise between these two conditions.

Instructions for Report Statement No. 25. In this experiment, you showed that decreasing the resistance value in the discharging circuit of a condenser will reduce the time constant of the circuit. It can also be shown that decreasing the capacity of the condenser without changing the resistance reduces the time constant.

For Report Statement No. 25, you will prove the preceding statement by reducing the capacity to .125 mfd. and discharging this through the 10-megohm input resistance of the N. R. I. Tester.

To carry out this experiment, connect the two .25-mfd. condensers in series by soldering a lead of one condenser temporarily to a lead of the other condenser; this gives you a combined capacity of .125 mfd. between the two free leads of this condenser group. Push one free condenser lead into the $+V_{DC}$ jack of the N. R. I. Tester, and push the other free condenser lead into the $-V_{DC}$ jack. With the selector switch still at *V*, turn on the tester, then charge the .125-mfd. capacity with a 4.5-volt d.c. source (use your two test leads and the three dry cells in series for this purpose; connect the + terminal of the cell group to the condenser lead in the $+V_{DC}$ jack with the red test lead, and connect the — terminal of the cell group to the condenser lead which is in the $-V_{DC}$ jack). Remove the charging source. Estimate the number of seconds it takes for the meter pointer to drop from 4.5 volts down to 1.5 volts on the *DC* scale while discharging through the 10-megohm resistance of the N. R. I. Tester, turn to the last page, and place a check mark after the result you obtain.

EXPERIMENT 26

Purpose: **To demonstrate that direct current will flow through a coil, and to prove that the d.c. voltage drop produced across a coil by current flow depends solely upon the value of the direct current flowing and the d.c. resistance of the coils.**

To demonstrate that direct current will not flow through a paper condenser.

To demonstrate that direct current will flow through an electrolytic condenser, and to show that the value of the current will change when the polarity of the condenser connection is reversed.

Step 1. To study the characteristics of a coil in a direct current circuit, set up a series circuit like that shown in Figs. *17A* and *17B*, consist-

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
1	ACROSS COIL	.9	.9
	ACROSS 1000Ω	3.7	3.7
2	ACROSS 200Ω	.9	.7
	ACROSS 1000Ω	3.9	3.9
3	ACROSS 1000Ω	0	0
	ACROSS .25 MFD.	4.5	4.5
4	RESISTANCE OF .25 MFD. COND.	R= 110 MEG.	R= 100 MEG.
5	ACROSS 40,000Ω		.1
6	ACROSS 40,000Ω		1.7

TABLE 26. Record your results here for Experiments 26.

ing of flashlight cells *A*, *B* and *C*, the 10-henry choke coil (Part *3-10*), and one 1,000-ohm resistor (Part *3-5A*). With your N.R. I. Tester set for use as a 0-4-5-volt d.c. voltmeter (range *V*, with the test leads in the V_{DC} jacks), measure the voltage across the choke coil and across the resistor, and record each value in Table *26*. As soon as you have finished, open the circuit by disconnecting one coil lead, and turn off the N. R. I. Tester.

Step 2. To demonstrate that a coil in a d.c. circuit acts exactly like a resistor having the same ohmic value as the coil, replace the 10-henry choke coil with a 200-ohm resistor (Part *3-4*) and complete the series circuit connection so that your set-up corresponds to the circuit diagram in Fig. *18*. Now repeat the measurements of Step 1, measuring the voltage across each part in turn to see if the resistor gives circuit values the same as were obtained for the coil. Record your results in Table *26*. Open the circuit and turn off the N. R. I. Tester as soon as you have finished measurements.

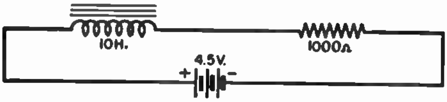

FIG. 17A. Schematic circuit diagram for Step 1 of Experiment 26.

A 200-ohm resistor is used in place of the coil, because the coil has a d.c. resistance of about 200 ohms.

FIG. 17B. Method of measuring the voltage across the 1,000-ohm resistor in the coil-resistor circuit which you set up for Step 1 of Experiment 26.

Step 3. To study the behavior of a paper condenser in a d.c. circuit, connect the three cells in series with the 1,000-ohm resistor (Part *3-5A*) and the .25-mfd. paper condenser (Part *3-2A*), as shown in Fig. *19*. Measure the voltage across the resistor and the condenser, and record your results in Table *26*. Open the circuit and turn off the N.R.I. Tester.

Step 4. To confirm the results obtained in Step 3, measure the resistance of your .25-mfd. condenser by using the highest resistance range of the N.R.I. Tester.

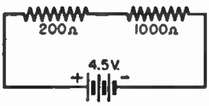

FIG. 18. Schematic circuit diagram for Step 2 of Experiment 26.

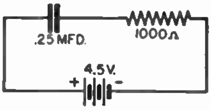

FIG. 19. Schematic circuit diagram for Step 3 of Experiment 26.

Before making a resistance measurement with the N.R.I. Tester, it is necessary to adjust the ohmmeter to zero. Set the selector switch to *MEG.*, short the *R* jacks so as to give zero external resistance (by plugging the test probes into these jacks and placing one test clip on the other clip), then adjust the potentiometer with a screwdriver until the pointer is at zero at the right-hand end of the *R* (top) scale.

After making the ohmmeter zero adjustment, leaving the selector switch set at *MEG.*, remove the test leads, then insert the condenser leads in the *R* jacks as shown in Fig. *20*, while watching the meter pointer. Do not touch the condenser leads with your fingers while doing this. Hold the condenser in this position until the meter pointer has come to rest definitely. Tap the top of the meter lightly with your finger to make sure the pointer has reached its final position, then read the meter on the *R* scale and record your reading in Table *26* as the resistance of the .25-mfd. condenser in megohms.

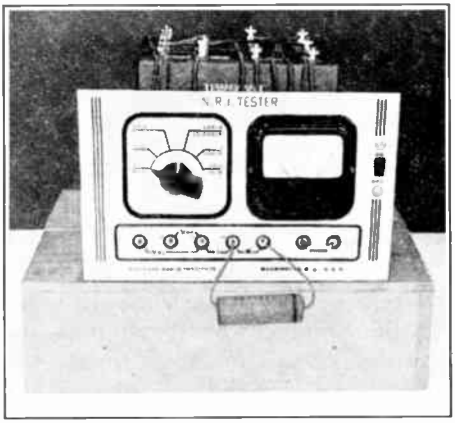

FIG. 20. Method of measuring the resistance of a .25-mfd. condenser with the N.R.I. Tester. Resistances up to 100 megohms can be measured with the N.R.I. Tester in this manner when the selector switch is set at *MEG.*

When the selector switch of the N.R.I. Tester is set at *MEG.*, and the *R* jacks are being used, your instrument is serving as a 0-100-megohm ohmmeter, and its indications are read directly in megohms on the *R* scale at the top of the meter.

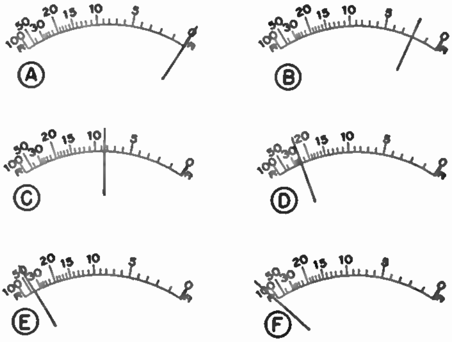

FIG. 21. Examples illustrating how to read the *R* scale on the meter of your N.R.I. Tester. The readings are as follows: *A*—0; *B*—2.0; *C*—8.5; *D*—24; *E*—40; *F*—INFINITY.

You should have no difficulty in reading the *R* scale after your experience with the *DC* scale and scale I_M. The only thing you should watch for is the fact that this scale reads from right to left. Between 0 and 20 on this scale, each small division represents 1. Between 20 and 30, each small division represents 2.

Readings for six different positions of the pointer on the *R* scale are indicated in Fig. *21.* Study each one of these carefully until you are certain you know how to read this scale, for you will use the ohmmeter scale extensively in your practical demonstration course and in actual radio work.

After completing resistance measurements, be sure to restore the original calibration. This can be done in a moment, simply by moving the calibrating clip to its calibrating position on —7½C and readjusting the potentiometer to give a meter reading of 1.5 on the *DC* scale, then returning the clip to —9C.

START. ✓

Step 5. To determine how an electrolytic condenser behaves in a d.c. circuit, connect one section of the dual 10-mfd. electrolytic condenser (Part *3-3*) in series with a 40,000-ohm resistor (Part 3-6A) and a series-connected group of three flashlight cells, as shown in Figs. *22A* and *22B*.

Correct connections for the electrolytic condenser are shown in Fig. *22B*. Observe that the three outside lugs, two with holes and one without, are all a part of the metal housing of the condenser; internally, this housing is connected to the — terminals of both 10-mfd. electrolytic condenser sections. The two terminal lugs in the center, one having a triangular cut-out alongside it in the fiber base, and the other having a square cut-out in the base, are the + terminals of the condenser sections.

Since both sections are of the same value in this particular dual unit, it does not matter which central lug you use for the + terminal of your electrolytic condenser. Of course, you can use either of the outer lugs for the negative terminal, since they are connected together anyway through the housing.

Observe that the negative terminal of the electrolytic condenser is connected to the negative terminal of the cell group in the circuit of Fig. *22B*. This is the correct method of connecting an electrolytic condenser to a circuit in which d.c. voltage is present.

With the N. R. I. Tester being used as a 0-4.5-volt d.c. voltmeter, measure the voltage across the 40,000-ohm resistor and record your value in Table *26*.

Step 6. Reverse the connections to the electrolytic condenser in the circuit of Fig. 22A, so that the + terminal of the condenser now goes to the — terminal of the cell group. Again measure the voltage across the 40,000-ohm resistor, and record your result in Table *26*.

Discussion: The resistance of the coil which you used in Step 1 is about 200 ohms (230 ohms to be exact, but we can consider this to be 200 ohms for all practical purposes). Adding 200 ohms to 1,000 ohms (the resistor value) gives a total circuit resistance of 1,200 ohms. We know that three dry cells connected in series aiding give a voltage of 4.5 volts, so we can easily determine the circuit current by means of Ohm's Law. The formula to be used is: $I = E \div R$; dividing 4.5 by 1,200 gives .00375 ampere, and this is equal to 3.75 ma.

Your measurement for Step 1 should confirm the 3.75-ma. value for the circuit current. You will recall that the voltage measured across a 1,000-ohm resistor corresponds to the current through that resistor in ma.; therefore, if you measured approximately 3.75 volts across the 1,000-ohm resistor, you know that you performed the experiment correctly.

A current of 3.75 ma. flowing through the 200-ohm coil will develop across this coil resistance a voltage of 200 × .00375, or .75 volt. If the voltage which you measured across the coil was approximately ¾ of a volt, you have confirmed the basic fact that a coil acts exactly like a resistance in a d.c. circuit. In other words, the only thing which limits the flow of current through a coil is the resistance of the wire used in winding the coil.

A coil is intended primarily for use in a.c. circuits, for there it has a reactance which opposes the flow of alternating current.

Step 2 shows even more convincingly the resistive nature of a coil in a d.c. circuit. This time, the resistor which replaced the coil in your circuit has about the same ohmic value as the coil. Therefore, your measured voltage values across the 200 and 1,000-ohm resistors should be essentially the same as in Step 1.

When the voltage across the condenser is measured in Step 3, you find that it is equal to the source voltage of 4.5 volts. Actually, the voltage is zero at the start, and builds up gradually to this final value as the condenser becomes charged.

When you measure the resistance of the .25-mfd. condenser in Step 4, you encounter the same charging phenomenon at first. The meter swings upscale, then gradually swings back to the left. You must wait until the pointer has stopped moving before taking a reading. If your condenser is in good condition, it will have a resistance above 50 megohms.

The one type of condenser which has a fairly low resistance is the electrolytic condenser. Between the plates of an electrolytic condenser is a paste or liquid which has considerably lower resistance than the mica, paper or air used between the plates in other condensers. Furthermore, an electrolytic condenser will allow more direct current to flow in one direction than in the other. This is why you must always consider polarity when connecting an electrolytic condenser.

The correct polarity for an electrolytic condenser is always such that the — terminal of the condenser goes to the — terminal of the voltage source; this is the connection we use in Step 5. The voltage measured across the 40,000-ohm resistor is an indication of the amount of current flowing through the condenser. We are not concerned with the exact current value at present, even though we could compute it by means of Ohm's Law. The important thing is to compare the measured voltage in Step 5 with the measured voltage in Step 6. You should obtain a higher voltage in Step 6, indicating that a higher value of direct current flows through an electrolytic condenser when it is improperly connected.

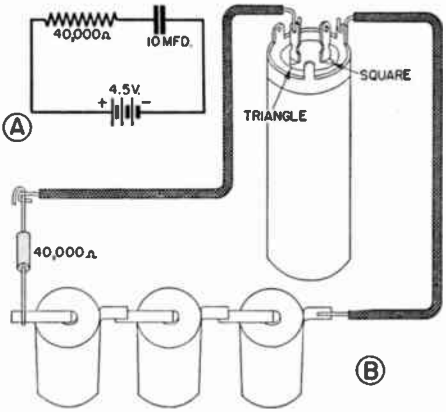

FIG. 22. Schematic (*A*) and semi-pictorial (*B*) circuit diagrams for Step 5 of Experiment 26.

Practical Extra Information. Your results in Steps 5 and 6 indicate that an electrolytic condenser has a definite resistance, and that this resistance is lower for an improper connection than for the correct polarity of connections. Since an electrolytic condenser is primarily intended for use as a capacitance, it is desirable to keep direct current through it at a minimum. With improper polarity of connections, excessive current through the condenser causes it to overheat and destroy itself.

Instructions for Report Statement No. 26. Radio servicemen frequently find it necessary to make continuity tests in order to determine whether a complete d.c. circuit exists between any two points in a piece of radio

Check information PART 3-8

apparatus. Resistances of various parts in a circuit must also be checked to determine whether any part is shorted or open. In many circuits, the part which is to be tested may be shunted by a paper condenser. You have proved that a paper condenser will not conduct direct current once it is charged; this means that you can ignore the presence of a paper condenser across a part if you know that the condenser is in good condition. In practical radio work, you can seldom be sure that a condenser is in good condition, so it is best to disconnect shunt condensers when making continuity tests.

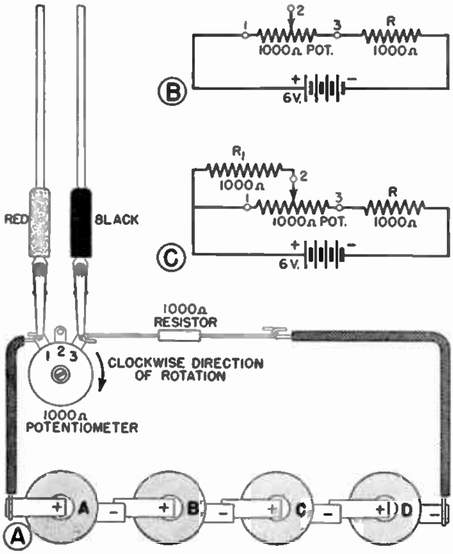

FIG. 23. Semi-pictorial (*A*) and schematic (*B* and *C*) circuit diagrams for Experiment 27.

For this report statement, make an additional test of this statement by setting up the circuit of Fig. *18*, connecting a .25-mfd. condenser across the 200-ohm resistor, and measuring again the d.c. voltage across the 1,000-ohm resistor. Compare the measured voltage value with that obtained originally for this circuit set-up, then turn to the last page and place a check mark after the answer you obtain.

EXPERIMENT 27

Purpose: **To show that during no-load conditions the voltages across various parts of a voltage divider will divide exactly according to resistance; to show that application of a load across a part of the voltage divider affects the division of voltages.**

Step 1. To set up a simple voltage divider circuit, connect together in series the four flashlight cells, the 1,000-ohm potentiometer (Part *3-8*) and the 1,000-ohm resistor *R* (Part *3-5A*) according to the semi-pictorial wiring diagram in Fig *23A*, so that you will have the circuit represented by the schematic diagram in Fig. *23B*. Use temporary soldered joints throughout. The potentiometer and the 1,000-ohm resistor can be placed on the table, and connected to the group of four cells with lengths of hook-up wire as shown. Number the potentiometer lugs *1*, *2* and *3* as indicated in Fig. *23A*, by writing on the fiber base of the potentiometer alongside each lug.

Measure the voltage drop across the potentiometer by placing the red clip on terminal *1*, and placing the black clip on terminal *3*, as shown in Fig. *23A*. Set the selector switch at *V*, plug the test probes into the V_{DC} jacks (remember that the red probe goes into the + jack), turn on the N. R. I. Tester, read the meter on the *DC* scale, and record the value in Table *27* as the voltage in volts across the 1,000-ohm potentiometer.

Now measure the voltage across the 1,000-ohm resistor *R* and record its value in Table *27*.

Step 2. To demonstrate how the potentiometer can provide a variable voltage, measure the voltage between movable terminal *2* and fixed terminal *1* on the potentiometer while rotating the potentiometer shaft from one ex-

STEP	NATURE OF MEASUREMENT	YOUR VOLTAGE IN VOLTS	N.R.I. VOLTAGE IN VOLTS
1	VOLTAGE ACROSS 1000Ω POT.	3.1	2.9
	VOLTAGE ACROSS 1000Ω RES. R		3.1
2	VOLTAGE AT 0 ROTATION	0	0
	VOLTAGE AT ¼ ROTATION	6	.6
	VOLTAGE AT ½ ROTATION	1.6	1.4
	VOLTAGE AT ¾ ROTATION	2.4	2.1
	VOLTAGE AT FULL ROTATION	3.1	2.9
4	VOLTAGE ACROSS 1000Ω POT.	3.1	2.1
	VOLTAGE ACROSS 1000Ω RES. R	3.9	3.9
	VOLTAGE AT 0 ROTATION	0	0
	VOLTAGE AT ¼ ROTATION	5	.5
	VOLTAGE AT ½ ROTATION	1.2	1.1
	VOLTAGE AT ¾ ROTATION	1.6	1.4
	VOLTAGE AT FULL ROTATION	2.1	2.1

TABLE 27. Record your results here for Experiment 27.

treme to the other. Do this by placing the red clip on terminal *1* and the black clip on terminal *2* (terminal *2* goes to the movable contact, as you can readily see by studying the construction of the potentiometer). The potentiometer has a slotted shaft, which can readily be rotated by inserting a screwdriver in the slot. After rotating the potentiometer back and forth a few times to see how the meter pointer behaves, rotate the potentiometer to the extreme clockwise position, read the voltage on the *DC* scale of the meter, and record it in Table *27* as the voltage for zero rotation. Now rotate the potentiometer through approximately ¼ of its complete movement, read the voltage again, and record it in Table *27* as the voltage for ¼ rotation. Repeat for ½, ¾ and full rotation of the potentiometer, recording the voltage in Table *27* each time.

Step 3. To prove that rotation of the movable contact of the potentiometer has no effect upon the voltage across the potentiometer when there is no load, connect the 0-4.5-volt d.c. voltage range of the N. R. I. Tester across the potentiometer (to terminals *1* and *3*) and watch the meter while you rotate the potentiometer shaft back and forth.

Step 4. To study the action of your voltage divider circuit under loaded conditions, connect a 1,000-ohm resistor R_1 (Part *3-5B*) between terminals *1* and *2* of the potentiometer by means of temporary soldered hook joints, as indicated in the schematic circuit diagram in Fig. *23C,* so that this resistor will serve as a load across one section of the potentiometer. Rotate the potentiometer shaft to its extreme counter-clockwise position, so that R_1 is in parallel with the entire resistance of the potentiometer, then repeat each of the measurements and tests called for in Steps 1 and 2 and record your results in Table *27.* Now disconnect one battery lead to open up the circuit and conserve battery life.

Discussion: Theoretically, the voltages which you measure across the 1,000-ohm resistor and 1,000-ohm potentiometer in Step 1 should be equal; actually, they may not be equal for the reason that manufacturing tolerances may make the values of these two parts higher or lower than 1,000 ohms. Therefore, with the 6-volt d.c. source, you should obtain somewhere around 3 volts across each of these parts. In other words, resistances of equal value connected in series will divide a voltage in half.

With essentially 3 volts across the entire potentiometer, you would expect to secure half of this value, or 1.5 volts, when the movable arm is at the halfway position in Step 2. Likewise, at the ¼ and ¾ positions, you would expect approximately .75 volt and 2.25 volts respectively. If you secure approximately these values in Step 2, you can consider your work as satisfactory.

Step 2 thus shows that the varying voltage obtainable from a potentiometer is proportional to the resistance across which the voltage is obtained when there is no load connected across this resistance. This method for obtaining a variable voltage is widely used in radio receivers for providing a control over volume.

Varying the position of the movable arm of the potentiometer in Step 3 has no effect upon the voltage across the potentiometer, simply because nothing is connected to the movable arm.

When you connect a 1,000-ohm load between the movable terminal and one end terminal of the potentiometer in Step 4, and rotate the potentiometer to its extreme counter-clockwise position, this 1,000-ohm load is in parallel with the full 1,000 ohms of the potentiometer. Two equal resistors in parallel always give a combined value equal to half that of one resistor, and consequently the resistance between terminals *1* and *3* in your circuit is now 500 ohms. The voltage drop across this 500 ohms should be only half the voltage drop across the 1,000-ohm fixed resistor; if you measured about twice as much voltage across resistor *R* as across the potentiometer, you verified this fact.

When the potentiometer arm is in its mid-position, you have the 1,000-ohm load shunted across half of the potentiometer resistance, which is 500 ohms. A 1,000-ohm resistor in parallel with a 500-ohm resistor gives a resultant or combined resistance of 333 ohms,[*] and this 333-ohm resistance acts in series with the remaining 500-ohm section of the potentiometer and the 1,000-ohm fixed resistor to give a total circuit resistance of 1,833 ohms. By means of Ohm's Law now, it is possible to compute what the voltage drop should be across each section of this circuit.

Computation. To find the circuit current, divide 6 by 1,833. This gives approximately .0033 ampere. To obtain the voltage drop across any section, we simply multiply this current value by the resistance of that section. Thus, the voltage drop across 1,000-ohm resistor *R* will be approximately 1,000 × .0033, or 3.3 volts. Across the unloaded 500-ohm section of the potentiometer, the drop should be 500 × .0033, or about 1.6 volts. Across the loaded section of the potentiometer (across R_1), the drop should be 333 x .0033, or about 1.1 volts, when the arm is at the mid-position. If you measured approximately this last value of 1.1 volts for the ½-rotation position in Step 4, you can consider your work satisfactory. Observe that you get less voltage across the loaded section of the potentiometer than across the unloaded section; this shows that the presence of the load disturbs the normal distribution of voltages in a voltage divider circuit.

Practical Extra Information. The important fact to remember in connection with Step 4 is that for a given setting of the potentiometer arm, the voltage will be less with a load than without a load. Furthermore, the lower the ohmic value of the load, the lower will be the voltage obtained. However, adjusting the potentiom-

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[*] The method of calculating this combined resistance of two resistors in parallel is given here for students who are interested:

$$R = \frac{R_1 \times R_2}{R_1 + R_2} \qquad R = \frac{1{,}000 \times 500}{1{,}000 + 500}$$

$$R = \frac{500{,}000}{1{,}500} \qquad R = 333 \text{ ohms}$$

eter will compensate for increased load and give the required voltage in most circuits.

In the voltage divider circuits of radio receivers, fixed resistors are generally used in place of potentiometers. This is possible because the value of the load across each resistor section is known, and its effect upon the voltage can be calculated by the set designer and compensated for.

Instructions for Report Statement No. 27. In the variable voltage divider circuit shown in Fig. *23B*, the fixed 1,000-ohm resistor serves the purpose of reducing the maximum voltage obtainable across the potentiometer. You will encounter this series resistor quite often in radio circuits, for oftentimes the source has a far higher voltage than can safely be applied directly to the terminals of the potentiometer.

For this report statement, make an additional measurement to determine whether a change in the value of the fixed 1,000-ohm resistor will have any effect upon the voltage provided by the potentiometer. To do this, connect the N. R. I. Tester to measure the voltage between terminals *1* and *2* of the potentiometer, complete the battery circuit which was previously disconnected to conserve battery life, adjust the potentiometer until the N. R. I. Tester indicates the voltage of 2 volts, then take your other 1,000-ohm resistor and shunt it temporarily across the 1,000-ohm resistor already in the circuit so as to reduce this series resistance to 500 ohms. Note the change in the N. R. I. Tester reading, then turn to the last page and place a check mark after the answer in Report Statement No. 27 which describes your result.

EXPERIMENT 28

Purpose: **To show that coils and condensers offer a definite amount of opposition to the flow of current in an a.c. circuit.**

Step 1. To set up a power supply circuit which will give you a 5-volt

A. C. EXPERIMENTS

If you do not have 110 to 120-volt, 50 to 60-cycle a.c. power in your home or in the place where you plan to carry out future experiments in this practical demonstration course, you are temporarily excused from performing the a.c. experiments (28, 29 and 30). This applies also to students who have only 25 or 40-cycle power.

Read these experiments carefully, however, giving especial study to the discussions so that you understand the basic principles involved, but do not answer the last three questions in the report statements at the present time. In the margin alongside Report Statements 28, 29 and 30 on the last page, write in pencil the words *"NO A.C. POWER,"* and send in this last page for grading. Your grade for Manual 3RK will be based upon the seven experiments which you have performed. In the next assignment, you will be provided with special instructions for carrying out three similar a.c. experiments and future experiments requiring a.c. power.

If you *have 115-volt, 50 or 60 cycle a.c. power* in your home, you are expected to perform the following three experiments and answer *all ten* of the report statements.

a.c. voltage when it is connected to the 115-volt a.c. line, first secure a scrap piece of wood which is at least ½ inch thick and at least 5 inches wide and 7 inches long. Take the six-lug terminal strip (Part *3-12*) and mount it on this board with two of the ⅜-inch No. 6 round-head wood screws (Part *3-13*) in approximately the position shown in Fig. *24*.

Take the mounting bracket for the potentiometer (Part *3-9*) and mount it on your wood baseboard with the remaining ⅜-inch wood screw in approximately the position shown in Fig. *24*.

Mount the 1,000-ohm wire-wound potentiometer (Part *3-8*) on its mounting bracket by removing the hexagonal nut from the potentiometer shaft, inserting this threaded shaft through the large hole in the bracket from behind, replacing the nut on the shaft, and tightening the nut with ordinary pliers while holding the potentiometer so that its three terminal lugs are at the top (the correct position of the potentiometer is shown in Fig. *24*).

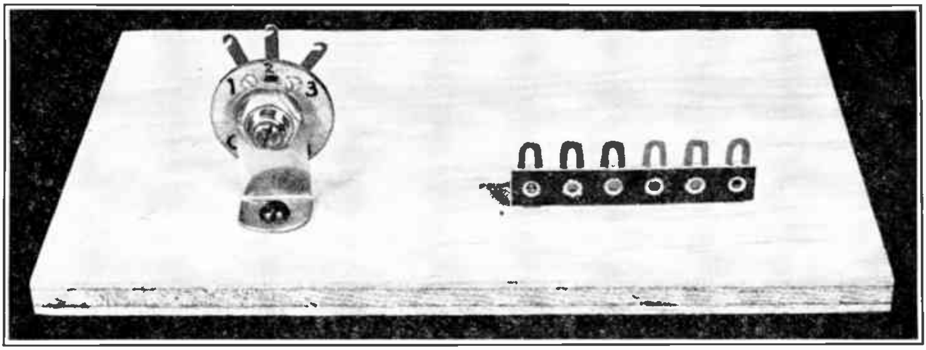


FIG. 24. For Step 1 of Experiment 28, mount the terminal strip and the potentiometer bracket in approximately the positions shown here, on a wooden base-board approximately 5" wide, 7" long and ½" thick.

Assemble your a.c. power supply circuit on the baseboard according to the schematic circuit diagram in Fig. *25A* by making the connections exactly as shown in Fig. *25B*, in the following order:

a. Number each of the lugs on the terminal strip in the manner shown in Fig. *25B* by placing the numbers on the baseboard directly under the respective lugs, and using either pencil, ink or crayon for marking purposes. The potentiometer terminals will already be numbered *1*, *2* and *3* from the previous experiment.

b. Connect the 1,000-ohm resistor (Part *3-5A*) to terminals *4* and *5* by means of temporary hook joints, but solder the joint at terminal *4* only.

c. With a suitable length of hook-up wire, connect potentiometer terminal *1* to terminal *7*, but solder only the joint at terminal *1*.

d. With a suitable length of hook-up wire, connect potentiometer terminal *2* to terminal *6*, soldering both joints this time.

e. With a suitable length of hook-up wire, connect potentiometer terminal *3* to terminal *5*, but solder only terminal *3*.

f. Take the four 40,000-ohm resistors (Parts *3-6A*, *3-6B*, *3-6C* and *3-6D*) and connect them all together in parallel, with 3-inch lengths of hook-up wire serving as the leads for the group, in the manner shown in Fig. *25B*. This can be done by cutting away or pushing back the insulation for about 1 inch from the end of a 3-inch length of hook-up wire, winding this bare end of the hook-up wire several times around the group of four resistor leads, then applying solder to the joint liberally so that it flows between all of the resistor leads. Do the same for the other group of four resistor leads. Now connect one of the leads for this resistor group to terminal *7*, and connect the other lead to terminal *9*, but solder only terminal *7* at this time. Four 40,000-ohm resistors in parallel give a combined resistance of 10,000 ohms.

g. Take the 5-foot length of power line cord with attached plug (Part *3-11*), twist the bare ends if they have become untwisted, connect one lead of this cord to terminal *9* by means of a temporary hook joint, and connect the other lead of this cord to terminal *5* in the same way. Solder both joints.

h. Check all connections carefully against the semi-pictorial wiring diagram in Fig. *25B*, for a single mistake here may result in your blowing the house fuse when you plug this circuit into the power line. Be sure that there are no wires or lumps of solder shorting together adjacent lugs on the terminal strip.

Step 2. To become familiar with the reading of the AC scale on the meter of the N. R. I. Tester, study carefully the actual-size reproductions of this scale in Fig. *26*. An analysis of the four examples which are given should enable you to read this scale at any position of the pointer, for the *AC* scale is read in essentially the same way as the *DC* scale.

The *AC* scale on your meter is used for all four of the a.c. voltage ranges: *V*, *3 × V*, *30 × V* and *100 × V*. When using the *V* range, read the voltage in volts directly on this scale. When using the *3 × V* range, multiply the reading on the *AC* scale by 3. When using the *30 × V* range, multiply the reading by 30. When using the *100 × V* range, multiply the reading by 100.

Step 3. To measure the voltages which are present across various parts of an a.c. voltage divider circuit when there is no load, first set the N. R. I. Tester to measure the highest a.c. voltage which you will encounter. This will be the 115-volt a.c. line voltage, so set the selector switch to *30 × V*. Plug the red probe into the left-hand V_{AC} jack (terminal *30*), and plug the black probe into the $-V_{AC}$ jack (terminal *28*), which is *THIRD* from the left.

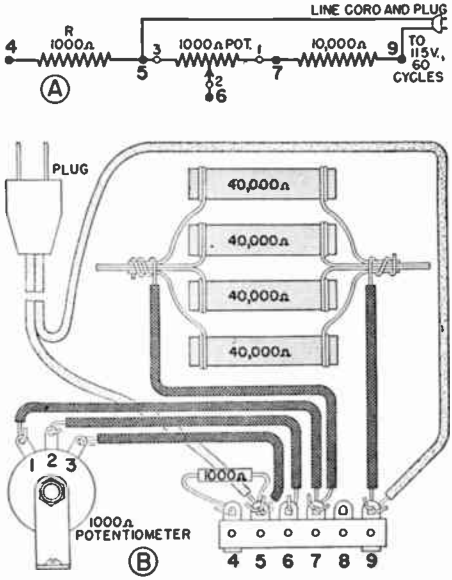


FIG. 25. Schematic (*A*) and semi-pictorial (*B*) circuit diagrams for the a.c. power supply source which you set up in Step 1 of Experiment 28.

Caution: It is extremely important that you perform all a.c. experiments on an insulated bench or table. An ordinary wooden table is ideal, as also is a wooden table covered with linoleum or oilcloth, but a porcelain-top table is unsatisfactory because the porcelain is applied to a metal base. A.C. experiments should be performed at a location where you are out of reach of any grounded objects such as a radiator, water pipe, gas pipe, metal electric conduit, outlet boxes, or damp concrete basement floors. If your experiments must be done in a basement, any inexpensive rug or piece of linoleum placed on the floor will eliminate the shock hazard from this source.

The most important precaution for you to observe, however, is never to touch a terminal at which a.c. line voltage may exist, if you can possibly avoid doing this. As an added precaution, use only one hand while working with electrical apparatus with the power on. If you should accidentally touch a high-voltage terminal with one hand, and no part of your body is grounded, there will be no danger of shock.

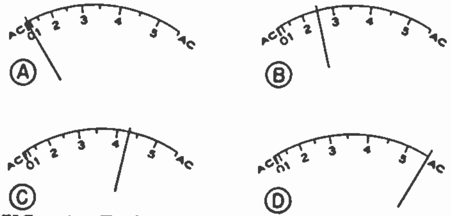


FIG. 26. To illustrate how the *AC* scale on the meter of the N.R.I. Tester is read, readings corresponding to four different positions of the pointer are given in these examples. The readings are as follows: *A*—.5V; *B*—2.5V; *C*—4.3V; *D*—5.5V.

Safety Rules for A.C. Circuits

Disconnect your equipment from the a.c. line at all times except when actually making a test or reading.

Do not allow any part of your body to come in contact with a grounded object while working with a.c. equipment.

Whenever it is necessary for you to handle equipment while power is on, use only one hand for this purpose. Many engineers keep the unused hand in their pocket to avoid using it unconsciously, such as for grabbing a part which may be falling over.

Always connect the black clip of the N. R. I. Tester to the a.c. terminal which is nearer to ground potential whenever making a voltage measurement. Observing this precaution may prevent you from getting a shock when you touch the panel or chassis of the N. R. I. Tester. When you do not know which of the a.c. terminals is grounded, measure between each of them and a ground wire; the one which gives a voltage reading to ground will be hot, so the other will be grounded.

To locate the terminal of your a.c. voltage divider which is nearer to ground potential, place the black clip on a ground wire going to any convenient ground such as a water pipe, and place the red clip on terminal *9*. Insert the power cord plug in the a.c. outlet, note the meter reading on the *AC* scale, then reverse the position of the plug in the outlet and again note the meter reading. In one position the reading should be essentially zero, and in the other position the reading should be almost 4 on the *AC* scale, indicating a voltage of about 4 × 30, or 120 volts since the *30* × *V* range is used.

The plug position which gives a reading near 4 is the safest position, so make a crayon mark both on the plug and on the outlet so that you will *always* replace the plug in this position during the next three experiments. This plug position makes terminal *9* hot, so *do not touch this terminal* (or the resistor leads on it) while power is on.

Read the meter on the *AC* scale while the plug is in the safest position, multiply the reading by 30, and record your result in Table *28* as the voltage in volts between terminal *9* and ground. Now pull out the plug.

Move the red clip to terminal *5*, leave the black clip on the ground wire, leave the N. R. I. Tester just as it is, then insert the plug into the wall outlet *in its safest position*.

Read the meter on the *AC* scale, and record your result in Table *28* as the voltage between terminal *5* and ground. Your result should be zero, because terminal *5* is now connected to the power line wire which is grounded at the power plant. Now pull out the plug, remove the black clip from the ground wire, and set aside the ground wire because it is no longer needed.

Now place the black clip on terminal *5*, place the red clip on terminal *9*, set the N. R. I. Tester to *30* × *V*, turn on the tester. insert the plug in the outlet, read the meter on the *AC* scale, multiply the reading by 30 and record your result in Table *28* as the a. c. line voltage between terminals *5* and *9*. Pull out the plug and turn off the N. R. I. Tester.

Measure the a.c. voltage across the 10,000-ohm resistor (the four 40,000-ohm resistors in parallel are equivalent to one 10,000-ohm resistor, and will therefore be referred to as a 10,000-ohm resistor during these experiments), by placing the back clip on terminal *7* (this is closer to ground than terminal *9*) and placing the red clip on terminal *9*. Turn on the N.R.I. Tester, insert the plug in the outlet, read the meter on the *AC* scale, multiply the result by 30, and record it in Table *28* as the voltage existing between terminals *7* and *9*. Pull out the plug and turn off the N. R. I. Tester.

Measure the voltage across the 1,000-ohm potentiometer by placing the black clip on terminal *5*, placing the red clip on terminal *7*, turning on the N. R. I. Tester with the selector switch still at *30* × *V*, and inserting the plug into the outlet. Read the meter on the *AC* scale and multiply the result by 30; if this result is below 16.5 volts (the maximum value on the next lower *AC* scale), rotate the selector switch in *3* × *V*. Read the meter again on the *AC* scale, multiply the reading by 3 this time, and record it in Table *28* as the voltage in volts between terminals *5* and *7*. Pull out the plug and turn off the N. R. I. Tester.

Step 4. To adjust the voltage between terminals 5 and 6 to 5 volts, place the black clip on *5*, and place the red clip on *6*. Set the N. R. I. Tester to the *3* × *V* range, turn on the switch, insert the power cord plug in an outlet, then rotate the potentiometer with a screwdriver until the meter pointer is approximately at 1.75 on the *AC* scale (corresponding to 5 volts on this scale). This value is safely within the next lower range of your meter, so change the selector switch to the *V* range and make a more accurate adjustment of the potentiometer to give meter reading of 5 on the *AC* scale. Pull out the plug and turn off the N. R. I. Tester, without changing the potentiometer setting.

Step 5. To measure voltage and current values for a 1,000-ohm resistor (R_1) which is connected between terminals 4 and 6 of the a.c. voltage divider to give the circuit shown in Fig. 27A, take one of your 1,000-ohm resistors (Part *3-5B*), shape the leads

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
3	VOLTAGE BETWEEN 9 AND GROUND	116	120
	VOLTAGE BETWEEN 5 AND GROUND	0	0
	VOLTAGE BETWEEN TERMINALS 5 AND 9	116	120
	VOLTAGE BETWEEN TERMINALS 7 AND 9	105	108
	VOLTAGE BETWEEN TERMINALS 5 AND 7	10.2	12
5	VOLTAGE ACROSS 1000Ω R_1	2.7	2.4
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	2.9	2.5
6	VOLTAGE ACROSS .5 MFD. C	4.9	4.9
	VOLTAGE ACROSS R (SAME AS CURRENT THRU C IN MA.)	.9	.9
7	VOLTAGE ACROSS 10 MFD. C	2.1	1.9
	VOLTAGE ACROSS R (SAME AS CURRENT THRU C IN MA.)	4.6	4.6
8	VOLTAGE ACROSS 10 HENRY L	4.7	4.7
	VOLTAGE ACROSS R (SAME AS CURRENT THRU L IN MA.)		.9

TABLE 28. **Record your results here for Experiment 28.**

so that one will touch terminal *6* when the other is on terminal *4* of the terminal strip mounted on your baseboard, tin the end of each lead liberally with rosin-core solder, apply surplus solder to the tip of your soldering iron, then hold the resistor against these terminals in the manner shown in Fig. *28*, and apply the soldering iron to each resistor lead in turn, long enough to fuse the solder and give a temporary soldered lap joint at each terminal.

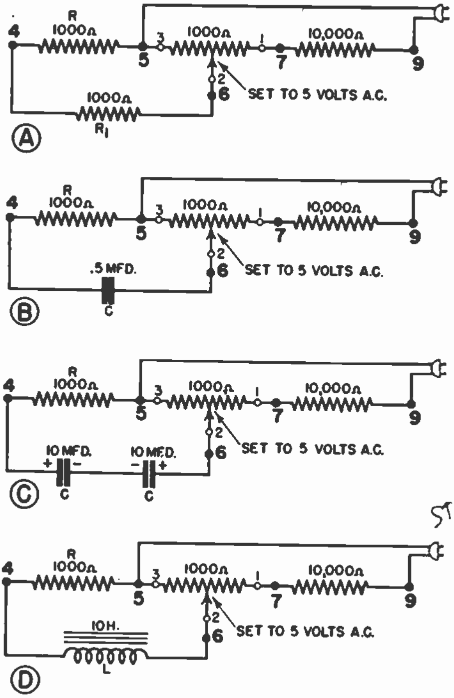


FIG. 27. Schematic circuit diagrams for the circuits which you set up in Steps 5, 6, 7 and 8 in Experiment 28 to determine how resistors, coils and condensers behave in 60-cycle a.c. circuits.

This 1,000-ohm resistor R_1 is now in series with 1,000-ohm resistor R previously mounted on the terminal strip between lugs *4* and *5*; resistor R provides a convenient means for determining the circuit current when various radio parts are connected between terminals *4* and *6*, for the voltage drop across a 1,000-ohm resistance is equal to the current in milliamperes through that resistance.

Connecting a load between terminals *5* and *6* in this manner will make the voltage between these terminals drop below 5 volts, so readjust this voltage between terminals *5* and *6* to 5 volts in the manner described in Step 4, then pull out the plug.

To measure the voltage across R_1, place the black clip on terminal *4* (this is nearer to ground potential) and place the red clip on terminal *6*. Insert the plug in the outlet, read the meter on the *AC* scale, and record the result in Table *28* as the voltage in volts across 1,000-ohm resistor R_1. Pull out the plug.

To measure the current through R_1, move the red clip to terminal *4*, move the black clip to terminal *5*, reinsert the plug, read the meter on the *AC* scale, and record this value in Table *28* as the voltage in volts across R. This will also be the value in ma. of the current through R_1. Pull out the plug, and turn off the N. R. I. Tester.

START

Step 6. To measure voltage and current values for a .5-mfd. capacity which is connected into an a.c. circuit having a 5-volt a.c. source, first disconnect 1,000-ohm resistor R_1 from terminals *4* and *6*, and remove the N. R. I. Tester clips. Connect a .5-mfd. capacity (two .25-mfd. condensers, Parts *3-2A* and *3-2B*, connected in parallel) to terminals *4* and *6* as indicated in Fig. *27B*. Do this by tinning the condenser leads, holding them against terminals *4* and *6*, and applying the heated soldering iron to fuse the solder and provide secure temporary soldered lap joints, just as you did for resistor R_1 in Step 5.

Adjust the voltage between terminals *5* and *6* to 5 volts again, by placing the black clip on *5* and the red clip on *6*, setting the N. R. I. Tester to the *3* × *V* range, and adjusting the potentiometer roughly to a meter reading of 1.75 on the *AC* scale, then switching to the *V* range and adjusting the potentiometer until the meter reads exactly 5 on the *AC* scale. This is the same adjustment as described in Step 4. Pull out the plug now.

To measure the voltage across capacity *C*, place the black clip on terminal *4* and place the red clip on terminal *6*. Turn on the N. R. I. Tester, leaving it set at the *V* range. Read the meter on the *AC* scale, and record the value in Table *28* as the voltage in volts across .5-mfd. capacity *C*. Pull out the plug.

To measure the current through *C*, place the black clip on terminal *5*, and place the red clip on terminal *4*. Insert the plug in the outlet, read the meter on the AC scale, and record the value in Table *28* as the voltage across *R*. This will also be the value in ma. of current through .5-mfd. capacity *C*. Pull out the plug, turn off the N. R. I. Tester, remove the two test clips, disconnect the .5-mfd. capacity, then separate the two .25-mfd. condensers. Do not straighten out the hooks in the condenser leads yet.

Step 7. To measure voltage and current values for a 10-mfd. electrolytic condenser connected according to the schematic circuit diagram in Fig. 27C, take two 3-inch lengths of red hook-up wire, connect one to each of the center terminal lugs of the dual 10 - 10 - mfd. electrolytic condenser (Part *3-3*), then connect one of these leads to terminal *4* and the other to terminal *6* by means of temporary soldered lap joints. This places the two sections of the condenser in series bucking, with their — terminals connected together internally through the common metal housing of the unit, but gives a resultant capacity which is essentially the same as the capacity of only one active 10-mfd. individual unit; this is true only with electrolytic condensers.

Adjust the potentiometer in the manner described in Steps 4 and 6, so as to give exactly 5 volts a.c. between terminals *5* and *6*, then pull out the plug.

To measure the voltage across the 10-mfd. capacity, place the black clip on *4*, place the red clip on *6*, insert the plug, read the meter on the *AC* scale, and record your result in Table *28* as the voltage in volts across the 10-mfd. capacity *C*. Pull out the plug.

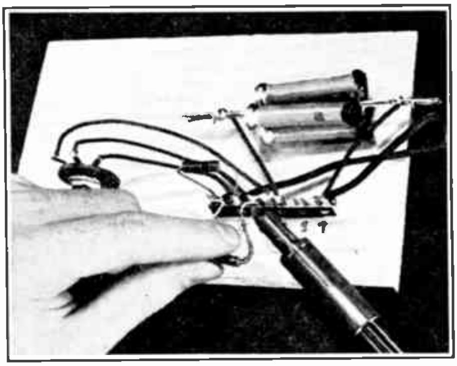


FIG. 28. This illustration shows you how to make a temporary soldered lap joint for the purpose of connecting a radio part temporarily between two terminals. This technique allows you to hold the part with one hand (instead of holding the solder in that hand), and gives a joint which can easily be disconnected.

To measure the current through the 10-mfd. capacity, place the red clip on terminal *4*, place the black clip on terminal *5*, insert the plug, read the meter on the *AC* scale, and record the value in Table *28* as the voltage across *R*. This will also be the current in ma. through the 10-mfd. capacity *C*. Pull out the plug, turn off the N. R. I. Tester, remove the clips, and disconnect the dual 10-10-mfd. condenser from terminals *4* and *6*.

Step 8. To study the action of a coil in an a.c. circuit, take the 10-henry choke coil (Part *3-10*), attach a 3-inch length of hook-up wire to each of its terminal lugs by means of a temporary soldered hook joint, connect one of these leads to terminal *4*, and connect the other lead to terminal *6*, so that you have the circuit arrangement shown in Fig. *27D*.

Adjust the potentiometer as previously described, to give exactly 5 volts a.c., then pull out the plug.

To measure the voltage across coil *L*, place the black clip on *4*, place the red clip on *6*, insert the plug, read the meter on the *AC* scale, and record the result in Table *28* as the voltage in volts across coil *L*. Pull out the plug.

To measure the current through coil *L*, place the black clip on *5*, place the red clip on *4*, insert the plug, read the meter on the *AC* scale, and record the result in Table *28* as the voltage across *R*. This will also be the current in ma. through the 10-henry coil *L*. Pull out the plug, turn off the N. R. I. Tester, remove the clips, then disconnect the coil but leave the two leads connected to the coil terminals. Leave the remainder of the circuit set up for the next experiment.

Discussion: If you have done any previous experimenting or if you have worked at all with a.c. house wiring, you undoubtedly know already that a 110-volt a.c. voltage can give you an unpleasant shock. Furthermore, under certain conditions this voltage can be dangerous. These dangerous conditions are quite easy to avoid, for they depend upon electricity going through your entire body, particularly through the region of the heart.

By keeping all parts of your body away from any grounded metal object and by touching radio apparatus with only one hand whenever there is a possibility that power might be on, you make it impossible for current to find a path through your body. Under these conditions, you can work with 110-volt a.c. voltages with perfect safety.

Every radio man must work extensively with 110-volt a.c. apparatus, so form the proper safety habits right from the start. Safety rules are even more important when working with ordinary a.c. radio receivers; here you encounter stepped-up a.c. voltages approaching 1,000 volts, which are considerably more dangerous than 110 volts, unless these same safety precautions are used.

Study of the schematic circuit diagram in Fig. *25A* will show that you voltage divider consists of a 10,000-ohm resistor and a 1,000-ohm potentiometer connected in series across the a.c. line. This gives a total of 11,000 ohms.

With no load connected across the voltage divider (Step 3), you should find that the voltages divide exactly in proportion to the resistances, just as in the case of the d.c. voltage divider used in the previous experiment. There should be ten times as much voltage across the 10,000-ohm resistor as there is across the 1,000-ohm resistor, and these two voltages should add up to the line voltage. Looking at it another way, the potentiometer resistance is only 1/11 of the total resistance, and consequently the potentiometer voltage should be only 1/11 of the total voltage.

If the line voltage in your case is slightly high, say about 120 volts, the voltage across the 1,000-ohm potentiometer will be about 11 volts. You are thus using this voltage divider to reduce the 120-volt line voltage to 11 volts a.c. for this experiment.

In Step 5, you use a 1,000-ohm resistor R_1 as a load across one section of the potentiometer, with a 1,000-ohm resistor *R* in series with this load for current-measuring purposes. The voltage drop across the 1,000-ohm resistor *R* is exactly equal in value to the current in milliamperes through the load.

When you turn on the power after connecting 1,000-ohm resistor R_1 to terminals *4* and *6*, you will find that the voltage between terminals *5* and *6* is about 1 volt lower than the original no-load value of 5 volts. This proves that the same action holds true for a.c. circuits as for d.c. circuits, wherein the placing of a load across a portion of a voltage divider reduces the voltage available at that portion of the divider.

Actually, in Step 5 you have two 1,000-ohm resistors connected in series across an a.c. voltage of 5 volts (between terminals *5* and *6*). According to Kirchhoff's Voltage Law, the voltages across the two resistors should add up to the 5-volt a.c. voltage available between terminals *5* and *6*. Furthermore, because the resistors are equal in value, the voltages across them should be equal (each should be 2.5 volts). Of course, practical conditions make it unlikely that the voltages will be exactly equal and practical limitations in your measuring instrument make it unlikely that the two measured voltages will add up to exactly 5 volts, but your results should be close enough to the expected values to verify the basic law involved.

If the 1,000-ohm resistor R_1 were shorted out, there would be only 1,000 ohms connected between terminals *5* and *6*, and you would measure the full source voltage across resistor *R* (between terminals *4* and *5*). This means that 5 ma. would be flowing through this resistor. If you obtain a load current reading of about 2.5 ma. with both the 1,000-ohm resistors serving as load in Step 5, you can say that a resistor has exactly the same current-limiting characteristics in an a.c. circuit as it has in d.c. circuits.

When using the N. R. I. Tester for voltage measurements, make it a practice to estimate first the maximum voltage which could exist between the points across which a measurement is to be made, then set the selector switch to a range which will include this maximum value. If your estimate is high and you find it difficult to read the meter accurately, simply lower the range one step at a time until you can secure a better scale reading.

You may observe that when using the N. R. I. Tester as an a.c. voltmeter on the *V* range, a meter reading can be obtained when only one test clip is connected to an a.c. circuit. This reading is obtained simply because the test leads are picking up stray a.c. energy due to the house wiring.

Even touching your finger to one of the *disconnected* test clips can cause an increase in the meter reading, for then your own body is picking up additional electrical energy, and the N. R. I. Tester is measuring your voltage with respect to the other leads. The distributed capacity between leads is sufficient to complete the circuit through the 10-megohm input resistance of the N. R. I. Tester, but does not affect meter readings at all when both clips are connected.

In Step 6, you have a 1,000-ohm resistor and a .5-mfd. capacity connected in series across the 5-volt a.c. source. When you add together the voltages which you measure across the condenser and the resistor, you will find that they come to considerably more than 5 volts. Kirchhoff's Voltage Law for a.c. circuits says, however, that you cannot add voltages arithmetically in a.c. circuits having condensers or coils. You must add the voltages vectorially, taking phase into account, for the condenser and resistor voltages are 90° out of phase.

When the N. R. I. voltage values

across the condenser and resistor are added together vectorially in the manner shown in Fig. *29A*, the result is about 5 volts. Your values should add vectorially to approximately 5 as well, but remember that exact agreement is seldom possible because of practical conditions.

Adding Voltages Vectorially. For convenience, let 1 inch represent 1 volt on your vector diagram, and use the resistor voltage as your reference vector. Choose a starting point for your diagram (point *S* in Fig. *29A*), then lay out horizontally to the right from this starting point a line (*IR* in Fig. *29A*) having a length which is proportional to the value of the voltage measured across 1,000-ohm resistor *R*. Place an arrow at the end of this line.

Next, from starting point *S* draw a vector for the voltage across the added part. Since it is a condenser, draw the vector straight down from the reference point, because the voltage across a condenser always lags the voltage across a resistor by 90°.

Having plotted your two vectors for Step 6, add them together by completing the rectangle as indicated with dotted lines in Fig. *29A*, then draw in the diagonal of the rectangle. This diagonal is the resultant vector, representing the sum of the two vectors acting 90° out of phase. Measure the length of this vector in inches; this value will be the resultant voltage in volts, and should be essentially 5 volts.

Electrolytic Condenser Characteristics. When two electrolytic condensers are connected in series but with their respective negative terminals tied together, as is done in Step 7, one condenser always retains its desired capacitive properties despite the continual reversal of the a.c. voltage which is applied to the condenser group. In other words, for any given point in the a.c. cycle, one condenser is acting as a true condenser but the other is merely acting as a conductive path. For this reason, the combined capacity of the two electrolytic condensers is only the capacity of one of the units.

As a matter of practical information, this series opposition method of connecting electrolytic condensers is employed in actual practice whenever electrolytics are to be used in a.c. circuits. Otherwise, a single electrolytic unit cannot be used as a condenser in an a.c. circuit.

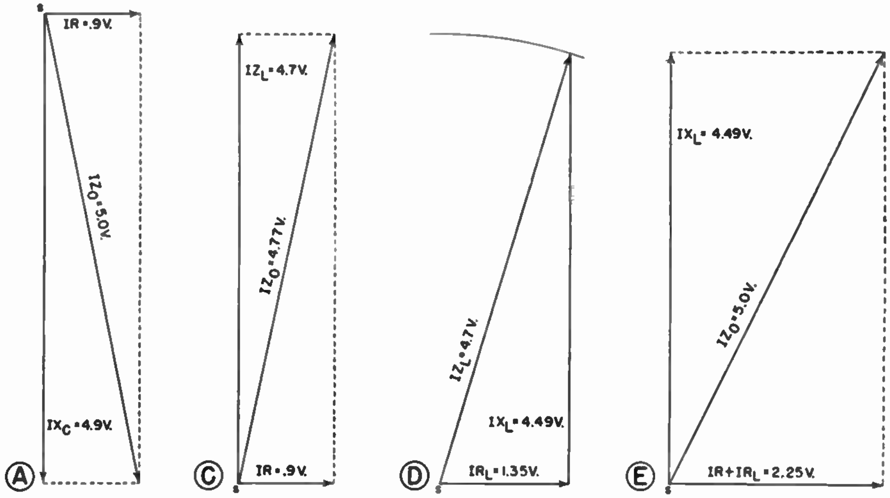
When Step 7 was carried out in the N. R. I. laboratory, values of 4.6 volts across the resistor and 1.9 volts across the condenser were obtained, as indicated in Table *28*. When these were added together vectorially in the manner shown in Fig. *29B*, a resultant voltage of essentially 5 volts was obtained, giving additional confirmation of Kirchhoff's Voltage Law for a.c. circuits.

Let us compare the relative current-limiting actions of the .5-mfd. and 10-mfd. condensers in this a.c. circuit. We will use the N. R. I. values here for comparison, but you can do the same thing with those values you measured.

The .5-mfd. condenser gave a current of .9 ma., while the 10-mfd. condenser gave a current of 4.6 ma. This indicates that both condensers serve to limit the value of a.c. current flowing, with the smaller condenser offering more opposition to current flow than did the larger condenser. This is exactly what you would expect from basic electrical principles, for the higher the electrical capacity value of a condenser, the lower is its reactance at a given frequency, and the less it limits current flow.

When the 10-henry choke coil was placed in series with the 1,000-ohm resistor as a load for a 5-volt a.c. source during the performance of Step 8 in the N. R. I. laboratory, a voltage of .9 volt was measured across the 1,000-ohm resistor, and 4.7 volts was measured across the coil. Adding these together vectorially at right angles in the manner shown in Fig. *29C* gives only 4.77 volts, which is a bit off from the applied a.c. voltage of 5 volts. The reason for this discrepancy is simply that the coil has considerable resistance, which is completely overlooked in the vector diagram in Fig. *29C*.

Your 10-henry coil has a d.c. resistance of about 200 ohms. When this coil is used in an a.c. circuit. however, certain a.c. losses make the resistance of the coil go up considerably. You will determine this value in the next experiment, but for purposes of clarifying the vector diagram in Fig. *29C*, let us assume that this a.c. resistance is 1,500 ohms.



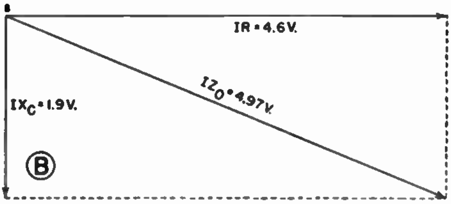


FIG. 29. These vector diagrams, based upon voltage values measured in the N.R.I. laboratory for the various steps of Experiment 28, prove definitely that Kirchhoff's Voltage Law holds true for a.c. circuits. One volt corresponds to ½-inch of vector length on these diagrams.

A voltage of .9 volt across the 1,000-ohm resistor indicates a current of .9 ma. through the circuit. This current flowing through the 1,500-ohm a.c. resistance of the coil gives a resistive voltage drop across the coil of .0009 x 1,500, which is 1.35 volts. Knowing that the total voltage across the coil is 4.7 volts and its resistive component is 1.35 volts, we can use the construction shown in Fig. *29D* to obtain the reactive component of voltage across the coil. Draw horizontal vector IR_1 to represent the voltage drop across the a.c. resistance of the coil. swing an arc whose radius is proportional to the measured coil voltage IZ_L, and draw a line vertically upward from the end of IR_L until it intersects the arc. The length of this vertical line will now correspond to IX_L, the reactive component of the coil voltage.

Adding the resistive component of the coil voltage to the voltage drop across the 1,000-ohm resistor gives 1.35+.9, or 2.25 volts. We plot this horizontally in Fig. *29E*, then draw in the reactive component of coil voltage as vector IX_L, at right angles to the first vector. Completing the rectangle now gives vector IZ_O, whose length will be proportional to the total voltage across the coil and resistor combined. For this vector we secure a value of 5 volts, which is correct.

This experiment has shown you quite clearly that we must take phase into account whenever adding voltages in a.c. circuits. You have thus demonstrated for yourself Kirchhoff's important voltage law for a.c. circuits.

Instructions for Report Statement No. 28. In an a.c. circuit, circuit conditions can be changed by shunting any part in the circuit with a resistor, a coil or a condenser, provided that the shunting part has a low enough resistance or impedance. For Report Statement No. 28, you will verify this.

Using the voltage divider circuit shown in Fig. *25,* connect between terminals *4* and *6* an 18,000-ohm resistor (Part *1-16*) and two .25-mfd. condensers, so that you have an 18,000-ohm resistor in parallel with a .5-mfd. capacity. Set the potentiometer to give maximum a.c. voltage (slightly over 10 volts) between terminals *5* and *6,* as measured with the N. R. I. Tester, then pull out the power cord plug. Place the black clip of the N. R. I. Tester on terminal *5,* place the red clip on terminal *4,* insert the plug, and read on the meter the voltage across 1000-ohm resistor *R* (use the *V* range). Now pull out the plug, disconnect the two .25-mfd. condensers, insert the plug again, and note the voltage now indicated across 1000-ohm resistor *R.* Turn to the last page and check the answer which describes your result. Now remove the 18,000-ohm resistor.

Start →

EXPERIMENT 29

Purpose: **To show that when a coil and condenser are connected in series, a resonant effect exists, and one part will partially or totally cancel the current-limiting effect of the other part; to show that the a.c. resistance of a coil is higher than the d.c. resistance of the coil.**

Step 1. Using the same a.c. voltage-dividing circuit employed in Experiment 28, connect one .25-mfd. condenser (Part *3-2A*) to terminals *4* and *6* by means of temporary soldered lap joints; the circuit is given in Fig. *30A.*

Place the black clip on terminal *5,* place the red clip on terminal *6,* set the selector switch to *3*×*V,* turn on the N. R. I. Tester, insert the plug in the outlet, and adjust the potentiometer until the meter reads approximately 4 volts (1.3 on the *AC* scale when using the *3*×*V* range). Now switch to the *V* scale and adjust accurately to 4 volts. (Note the change to 4 volts, as compared to the 5-volt value used in the previous experiment.) Pull out the plug.

To measure the voltage across the

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	N.R.I. VALUE IN VOLTS
1	VOLTAGE ACROSS .25 MFD. C	4	4.0
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	.3	.3
2	VOLTAGE ACROSS .25 MFD. C	5.4	5.4
	VOLTAGE ACROSS 10 HENRY L	1.	2.5
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	.75	1.0
3	VOLTAGE ACROSS .5 MFD. C	7.5	8.1
	VOLTAGE ACROSS 10 HENRY L	4.	7.5
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)	1.4	1.4
	VOLTAGE ACROSS .55 MFD. C	7.5	7.8
4	VOLTAGE ACROSS .5 MFD. C	10.9	11.4
	VOLTAGE ACROSS 10 HENRY L	6.	10.5

TABLE 29. Record your results here for Experiment 29.

.25-mfd. condenser, leave the red clip on *6* but move the black clip to terminal *4*. With the N. R. I. Tester still set at *V*, insert the plug, read the meter on the *AC* scale, and record the value in Table *29* as the voltage in volts across .25-mfd. condenser *C*. Pull out the plug.

To measure the current through the .25-mfd. condenser, place the black clip on *5*, place the red clip on *4*, and insert the plug. Read the meter on the *AC* scale and record the value in Table *29* as the voltage in volts across *R* and the current in ma. through *R* and *C*. Pull out the plug.

Step 2. To measure current and voltage values in a series circuit consisting of 1,000-ohm resistor R, 10-henry choke coil L and .25-mfd. condenser C, first disconnect the condenser lead from terminal *4*. Connect this condenser lead to one lead of the 10-henry choke coil (Part *3-10*), and connect the other choke coil lead to terminal *4*, as indicated in the schematic circuit diagram in Fig. *30B*.

Adjust the voltage between terminals *5* and *6* to *4* volts in the manner described in Step 1, then pull out the plug.

To measure the voltage across the .25-mfd. condenser *C*, place the red clip on terminal *6*, and place the black clip on the junction of the condenser and coil leads. With the N. R. I. Tester set to the *3*×*V* range, insert the plug, read the meter on the *AC* scale, multiply your result by 3, and record the result in Table *29* as the voltage in volts across .25-mfd. condenser *C*. Pull out the plug.

To measure the voltage across coil *L*, move the black clip to terminal *4*, and move the red clip to the junction of the coil and condenser leads. Leaving the N. R. I. Tester set at the *3*×*V* range, insert the plug, read the meter on the *AC* scale, multiply the value by 3, and record the result in Table *29* as the voltage in volts across 10-henry coil *L*. NOTE: If the voltage reading for the coil on the *3* × *V* range is less than 5.5 volts, change over to the *V* range in order to get a more accurate reading.

To measure the current in this series circuit, move the red clip to terminal *4* and move the black clip to terminal *5*. With the N. R. I. Tester set at *V*, read the meter on the *AC* scale and record the results in Table *29* as the voltage in volts across *R* and the current in ma. through the *R-L-C* circuit. Pull out the plug and remove the clips, but do not disturb other parts of the circuit.

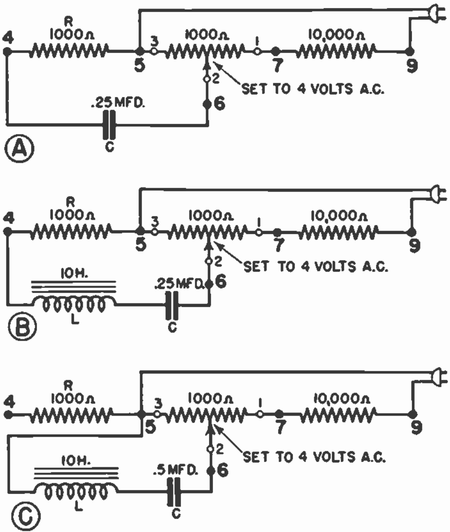


FIG. 30. Schematic circuit diagrams for Experiment 29.

Step 3. In order to repeat Step 2 with the condenser value in the circuit of Fig. 30B increased to .5 mfd., connect the other .25-mfd. condenser (Part *3-2B*) in parallel with the .25-mfd. condenser already in the circuit, using temporary soldered hook joints.

Now insert the plug in the outlet, readjust the voltage between terminals *5* and *6* to 4 volts, and repeat each of the measurements called for in Step 2. Record the results in Table *29*. Be particularly careful to set the voltmeter range first to *3×V* for each measurement, lowering to the *V* range only when you are certain the voltage will not overload the meter. Pull out the plug.

As a final measurement in this step, take the .05-mfd. condenser (Part *3-1*) and connect it in parallel with the group of two .25-mfd. condensers, soldering one lead by means of a temporary soldered lap joint to the common junction of the coil and condenser, but leaving the other lead unsoldered. With the red clip on terminal *6* and the black clip on the common junction of the condensers and the coil, and with the N. R. I. Tester set at *3×V*, insert the plug in the outlet. Grasp the .05-mfd. condenser by its paper housing and press the free lead against terminal *6*. Read the meter on the *AC* scale, multiply the value by 3, and record the value in Table *29* as the voltage in volts across the .55-mfd. capacity. Pull out the plug, turn off the N. R. I. Tester, remove the clips, and unsolder the .05-mfd. condenser completely from the circuit.

Step 4. To remove from your circuit the 1,000-ohm resistor which has been present in the previous steps for current-measuring purposes, disconnect the coil lead from terminal *4* and solder it instead to terminal *5*, as indicated in Fig. *30C*. Adjust the voltage between terminals *5* and *6* to exactly 4 volts in the manner previously described. Pull out the plug, set the selector switch to *30×V*, leave the red clip on terminal *6*, but move the black clip to the common junction of the condensers and coil. Insert the plug in the outlet, read the meter on the *AC* scale as accurately as possible, multiply the reading by 30, and record the result in Table *29* as the voltage across the .5-mfd. condenser. Pull out the plug.

The meter reading will be very low, below 1 on the scale, indicating a voltage value somewhere between 15 and 30 volts. You cannot estimate the value very accurately at this end of the scale, but can make a much more accurate reading on the *3×V* range if the voltage happens to be below the maximum value of 16.5 volts for this range. Therefore, switch to *3×V*. If the meter pointer swings to the upper end of the scale, read the meter on the *AC* scale, multiply the result by 3, and record it in Table *29* as the voltage for this measurement. If, however, the meter pointer merely vibrates around *0* when you switch to the *3×V* range, or reads slightly backward, do not attempt to get a more accurate reading. (It is a characteristic of the N. R. I. Tester to vibrate near *0* when overloaded on any of the *AC* voltage ranges. A similar action, usually in the form of a reversed reading, occurs during overloading on any of the *DC* voltage scales. Whenever an overload indication is secured, switch to the next higher range.) Remember that an overload will usually shift the *0* position of the pointer. As previously pointed out, this condition can be corrected simply by touching the calibrating clip momentarily to the —4½C terminal on the battery block.

To measure the voltage across coil *L*, place the black clip on terminal *5*, and place the red clip on the common junction of the coil and condenser leads. Set the N. R. I. Tester to *30×V*, insert the plug, read the meter on the *AC* scale, and multiply the value by 30. If the value comes out to be close to 16.5 or below this value, see if you can secure a more accurate reading on the *3×V* scale. Record your final value in Table *29* as the voltage across coil *L*. Pull out the plug, turn off the N. R. I. Tester, remove the clips, and disconnect the coil and the condenser group, but leave the two .25-mfd. condensers connected together.

Discussion: In Step 1, you have a .25-mfd. condenser connected in series with the 1,000-ohm resistor across the a. c. voltage source of 4 volts. At the power line frequency of 60 cycles, the reactance of a .25-mfd. condenser is 10,600 ohms.*

This is about ten times the ohmic value of the 1,000-ohm resistor, so you should expect to measure about ten times as much voltage drop across the condenser as you do across the resistor.

In the N. R. I. laboratory, the voltage across *C* was just about 4 volts. The voltage across the resistor was very low and difficult to read, with the estimated reading being .3 volt. If these voltages are added together vectorially, taking into account the fact that they are at right angles (90° out of phase), the resultant voltage across *R* and *C* together will still be about 4 volts, the source voltage. In other words, the circuit is essentially capacitive. The circuit current was about .3 ma. in this case.

The insertion of a 10-henry coil in series with the condenser and resistor to give the circuit shown in Fig. *30B*, while keeping the a.c. source voltage at 4 volts, will make both the circuit current and the condenser voltage go up. The fact that circuit current goes up is proof that the total impedance of the circuit has been lowered.

Now we obtain more voltage across the condenser than we have available at the source. From your fundamental course you learned, however, that the voltages across a coil and a condenser in a series circuit are 180° out of phase; this means that the combined voltage across them is the *difference* between their numerical values. The reason the current goes up is simply because the inductive reactance of the coil cancels out part of the capacitive reactance of the condenser, thereby lowering the total impedance in the circuit.

When the capacity in the circuit of Fig. *30B* is increased to .5 mfd. in Step 3, you will find that the coil, condenser and resistor voltages go up considerably. Coil and condenser voltages will be almost equal, indicating a condition very nearly approaching resonance. The difference between the coil and condenser voltages, when added vectorially to the resistor voltage, should presumably equal the source voltage of 4 volts. In the case of the N. R. I. values, however, adding the difference value of .6 volt at right angles to the resistor voltage of 1.4 volts does not give a value anywhere near 4 volts. We can be reasonably sure that this discrepancy is due to the a.c. resistance of the coil; furthermore, the voltage drop due to the a.c. resistance must be quite large.

It is possible to make measurements from which both the a.c. resistance of the coil and the Q factor of the coil can be computed. You do this by connecting the coil to a known a.c. voltage source in series with a condenser whose value will bring about the approximate condition of series resonance. Under this condition, the condenser and the coil both have maximum voltage values. The ratio of the coil voltage to the supply voltage is then the Q factor of the coil at the frequency used for the test (60 cycles in our case) and for the current value

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*The formula used for determining this reactance value is: $X_C = \frac{1,000,000}{6.28 \times f \times C}$, where X_C is the reactance in ohms, *f* is the frequency in cycles and *C* is the capacity in mfd.

flowing through the coil in the case of iron-core coils.

Knowing the Q factor, you can compute the a.c. coil resistance simply by dividing the reactance of the coil by the Q factor. This formula is correct for series resonant circuits, because at resonance the voltage of the source is dropped entirely in the coil resistance, and the a.c. resistance value therefore determines what the circuit current will be.

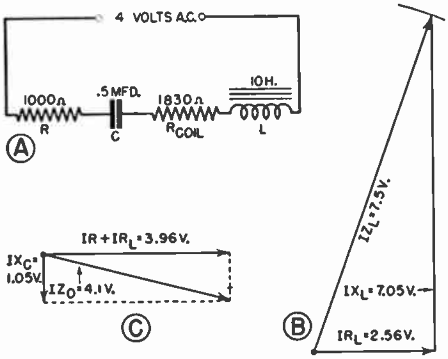


FIG. 31. Equivalent simplified circuit diagram corresponding to Fig. *30B*, and vector diagrams which prove that Kirchhoff's Voltage Law for a.c. circuits holds true in this particular circuit when tested out with the values obtained in the N.R.I. laboratory. One volt on these diagrams corresponds to ¼-inch of vector length.

As an example illustrating how the computations are made, we will use the values measured in the N. R. I. laboratory. We can assume that .5 mfd. tunes the coil essentially to resonance, particularly if the addition of the .05-mfd. condenser in Step 3 made the condenser voltage drop. We know that at resonance, the reactances of the coil and condenser are equal. We do not know the coil reactance because the inductance of this coil varies with the amount of current flowing through the coil (the rated value of 10 henrys applies only when rated current of 25 milliamperes is flowing). Therefore, we can compute the condenser reactance and assume that the choke will also have this reactance.

At 60 cycles, a .5-mfd. condenser has a reactance of about 5,300 ohms, so this will be used as our coil reactance value.

The measured N. R. I. voltage value across the choke coil in Step 3 was 7.5 volts. The supply voltage for the series resonant circuit is not 4 volts, however, because there is a drop of 1.4 volts across the 1000-ohm series resistor *R*. Subtracting 1.4 from 4 gives 2.6 volts actually acting on the coil and condenser.

Remembering that Q factor is equal to coil voltage divided by the *actual* supply voltage, we divide 7.5 by 2.6, and get 2.9 as the Q factor for the coil only. Now, dividing the coil reactance of 5,300 ohms by this Q factor value of 2.9 gives 1830 ohms as the a.c. resistance of the coil at 60 cycles.

Knowing the a.c. resistance value, we can use the values for Step 3 and see if we can make Kirchhoff's Voltage Law for a.c. circuits check in this case. The circuit diagram in Fig. *31A*, in which the a.c. resistance of the coil is separated from the coil inductance, will help you to understand this circuit.

To calculate the voltage drop across the a.c. resistance of the coil, multiply the a.c. resistance value by the circuit current value obtained in Step 3; 1830 x .0014, which is approximately 2.56 volts.

Next, we must find the true voltage drop across the inductance of the coil. The drop across the a.c. resistance of the coil is 2.56 volts, and the total coil impedance drop obtained in Step 3 is 7.5 volts. We draw a horizontal vector for 2.56 volts, then swing an arc having a radius proportional to 7.5 volts, and draw a line vertically upward from the end of the 2.56-volt vector until it intersects the arc, as shown in Fig. *31B*. The length of this vertical line will now be proportional to the voltage drop across the inductive reactance of the coil. Using the values measured at N.R.I., this drop came out to be 7.05 volts.

The resultant drop across the reactances in this circuit will be the difference between 8.1 and 7.05, or 1.05 volts. If we add this reactance drop at right angles to the total drop of 3.96 volts (2.56 + 1.4) across the 1,000-ohm resistor and the a.c. resistance of the coil in the manner shown in Fig. *31C*, we secure a resultant voltage vector which is just about 4 volts. Again we have confirmed Kirchhoff's Voltage Law for a.c. circuits.

This experiment has established the fact that in a series circuit, the reactances of a coil and a condenser cancel each other partially or completely. Furthermore, this experiment has proved definitely that the a.c. resistance of a coil is greater than its d.c. resistance. Finally, the experiment has shown that when a coil and condenser are connected in series, the combined reactance will be less than the largest individual reactance.

Instructions for Report Statement No. 29. An important principle to remember in connection with resonant circuits is that a change in the applied voltage does not affect the conditions of resonance.

With your parts connected according to the circuit shown in Fig *30C*, adjust the potentiometer until the a.c. voltage as measured between terminals *5* and *6* is 4 volts, then measure the voltage across condenser *C* while observing the safety precautions emphasized in previous a.c. experiments. Make a note of the voltage value observed, then readjust the voltage between terminals *5* and *6* to 2 volts, which is half of 4 volts, and measure again the voltage across condenser *C*. Compare the two voltage values measured across *C*, then turn to the last page and place a check mark after the answer which applies to your observation.

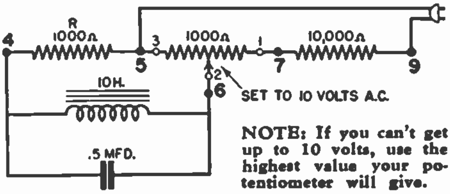
If the voltage across any part of the resonant circuit (such as across the condenser) drops proportionately when you reduce the source voltage to half its value, you have proved the statement brought forth above.

EXPERIMENT 30

***Purpose:* To show that the combined reactance of a coil and condenser connected in parallel in an a.c. circuit is higher than that of the lowest reactance in the combination.**

Step 1. With the a.c. voltage divider used in Experiments 28 and 29, connect the 10-henry coil between terminals *4* and *6* to give the same circuit arrangement as is shown in Fig. *27D*. Set the N. R. I. Tester to *3×V*, place the black clip on terminal *5*, place the red clip on terminal *6*, insert the plug in the outlet, turn on the tester, and adjust the potentiometer until you have 10 volts between terminals *5* and *6*, as indicated by a reading of 3.3 on the *AC* scale. Pull out the plug.

Place the black clip on terminal *5*, place the red clip on terminal *4*, insert the plug, and note the meter reading with the N. R. I. Tester set at *3×V*. If the actual voltage indication is below 5.5 volts, change to the *V* range to secure a more accurate reading. Record your final value as the current in ma. through *R* and *L*, then pull out the plug.



NOTE: If you can't get up to 10 volts, use the highest value your potentiometer will give.

FIG. 32. Schematic circuit diagram for Step 2 of Experiment 30.

Step 2. Place a .5-mfd. condenser in parallel with the coil as shown in Fig. 32 (use the two .25-mfd. condensers, Parts *3-2A* and *3-2B*, which you previously connected in parallel to give .5 mfd.). Use temporary soldered lap joints to terminals *4* and *6* for this purpose. Readjust the voltage between terminals *5* and *6* to 10 volts in the manner specified in Step 1, then pull out the plug. Place the black clip on terminal *5*, place the red clip on terminal *4*, leave the N. R. I. Tester set at the *V* range, turn on the N. R. I. Tester, reinsert the plug, read the meter on the *AC* scale, and record the result in Table *30* as the current in ma. through *R*, *L* and *C*. Pull out the plug, and turn off the Tester.

STEP	NATURE OF MEASUREMENT	YOUR VALUE IN MA.	N.R.I. VALUE IN MA.
1	CURRENT THRU R AND L	1.1	1.7
2	CURRENT THRU R,L AND C	.7	.5

TABLE 30. Record your results here for Experiment 30.

Discussion: In this experiment, you measure the current first through a 10-henry inductance having a reactance of approximately 5,300 ohms at 60 cycles, then through a parallel circuit consisting of the inductance and a .5-mfd. capacity which likewise has an impedance of 5,300 ohms. If you performed this experiment correctly, you should find that the mere shunting of the coil with this condenser serves to reduce the circuit current to 1/3 of the value for the coil alone. The parallel coil-condenser combination must therefore have a reactance of about 3 times the 5,300-ohm value for the coil alone, or 15,900 ohms.

The currents through the coil and the condenser are 180° out of phase, and therefore the total current drawn by these two parts must be equal to the difference between the currents through the individual parts.

The important fact for you to remember in connection with this experiment is that when a coil is shunted by a condenser, the combined impedance is greater than the lowest reactance.

Instructions for Report Statement No. 30. Suppose we repeated this experiment with a large condenser shunted across the choke coil, so that the condenser impedance is much lower than the coil impedance. Would the fundamental rule presented in this experiment still hold true? You can easily check this by making the following additional measurements.

Starting with your apparatus connected according to the circuit of Fig. *32*, disconnect both the 10-henry coil and the .5-mfd. condenser from terminals *4* and *6*, then connect to these same terminals a 10-mfd. capacity (your dual 10-10-mfd. condenser connected for a.c. operation, as was done in Step 7 of Experiment 28). Adjust the voltage between terminals *5* and *6* to 5 volts a.c., then measure the a.c. voltage across 1000-ohm resistor *R* (between terminals *4* and *5*). Remember that this voltage value is also the current in ma.; the higher this current, the lower is the impedance between terminals *4* and *6*.

Now connect to terminals *4* and *6* the 10-henry choke coil, so it is in parallel with the 10-mfd. capacity, and measure again the a.c. voltage across 1000-ohm resistor *R*. Check your answer in Report Statement No. 30. Pull out the plug, turn off the N. R. I. Tester, then disconnect the voltage divider.

IMPORTANT: Do not discard any of the parts supplied to you in N. R. I. radio kits before you have completed your course. The parts will be used again in later experiments.

INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 11 TO 20

2RK-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

A 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.

1950 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

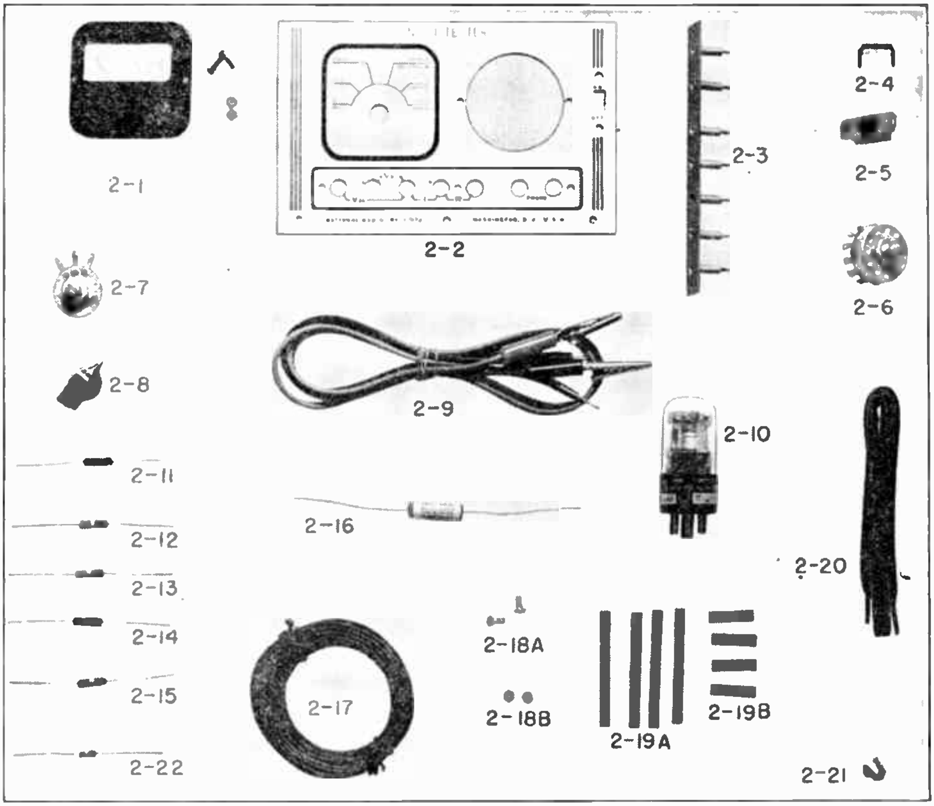

FIG. 1. The parts included in Radio Kit 2RK-1 are pictured above, and are identified in the list below. Note that the first numeral in each part number is 2; this enables you to identify these parts immediately as having been supplied to you in Radio Kit 2RK-1. When an experiment calls for a part having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

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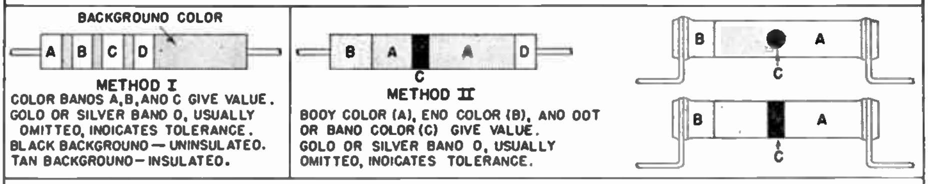
* These values are the new, post-war "standard" values and are therefore slightly different from the 6.7, .25, .2-megohm, and 900-ohm values shown in the various tables and diagrams.

RMA COLOR CODE FOR RESISTORS



METHOD I
COLOR BANDS A, B, AND C GIVE VALUE.
GOLD OR SILVER BAND D, USUALLY OMITTED, INDICATES TOLERANCE.
BLACK BACKGROUND — UNINSULATED.
TAN BACKGROUND — INSULATED.

METHOD II
BODY COLOR (A), END COLOR (B), AND DOT OR BAND COLOR (C) GIVE VALUE.
GOLD OR SILVER BAND D, USUALLY OMITTED, INDICATES TOLERANCE.

Color	Figure
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

COLOR A GIVES FIRST FIGURE OF RESISTOR VALUE.

COLOR B GIVES SECOND FIGURE OF RESISTOR VALUE.

COLOR C GIVES NUMBER OF CIPHERS FOLLOWING THE FIRST TWO FIGURES.

COLOR D: GOLD BAND INDICATES ± 5% TOLERANCE.
SILVER BAND INDICATES ± 10% TOLERANCE.
NO BAND INDICATES STANDARD ± 20% TOLERANCE.

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 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*.

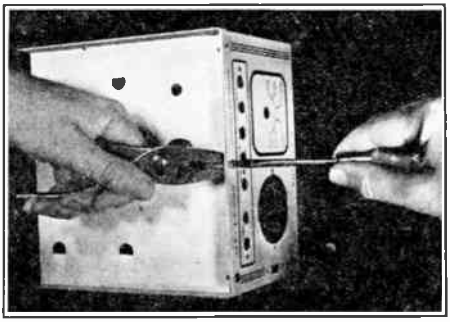


FIG. 5. Fasten the front panel to the chassis exactly as shown here. Use a medium-size screwdriver to tighten each screw while holding its nut with oridnary pliers.

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 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).

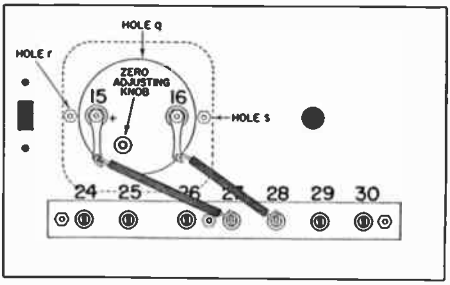


FIG. 6. ***Rear*** **view of front panel, showing how the meter and jack strip are mounted and connected together for the experiments which are to be made before assembling the NRI Tester. The chassis is not shown in this view, but should be attached to the bottom of the panel according to instructions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

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 readjust 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 hookup 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

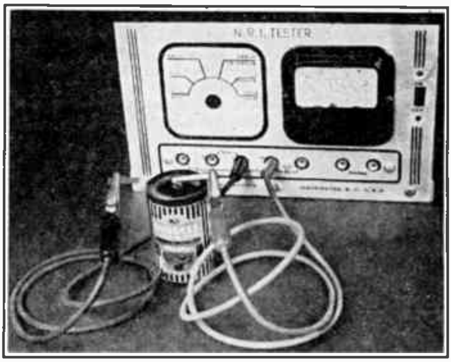


FIG. 7. Using the meter to demonstrate that a d.c. voltage source (the flashlight cell) has polarity. The meter pointer moves up-scale only when the cell is connected to the meter with proper polarity. The test leads were coiled merely to simplify taking the photograph; you will not have to bother with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

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* 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.

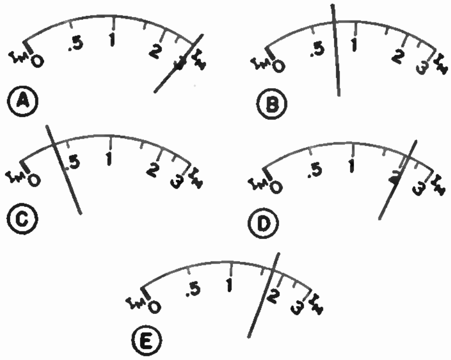


FIG. 8. Examples illustrating how to read scale I_M of your meter. The reading for *A* is 3 ma.; *B* is .75 ma.; *C* is .4 ma.; *D* is 2.1 ma.; *E* is to be read by you and the reading recorded in Report Statement No. 12. This scale indicates the current in milliamperes which is passing through the meter. 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 upscale 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

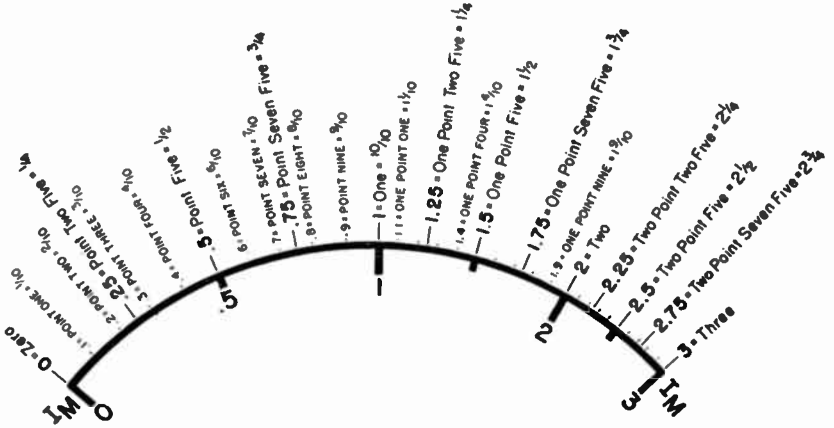


FIG. 8F. This enlarged view of the I_M scale of your meter can be used as a guide when questions arise in connection with meter readings. Various possible pointer positions are indicated by the thin lines above the scale. Estimated readings for typical positions are specified in three ways—first, as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

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. 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.

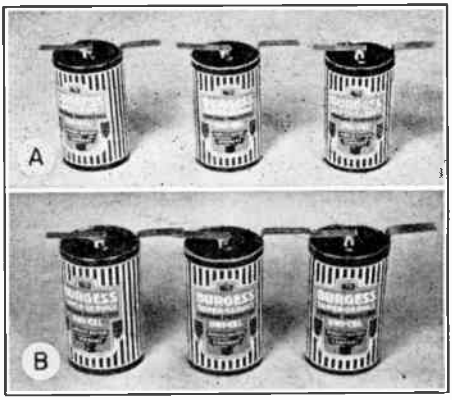


FIG. 9. Method of connecting three flashlight cells together in series aiding to permit obtaining three different values of d.c. voltage (1.5 volts, 3 volts and 4.5 volts).

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-

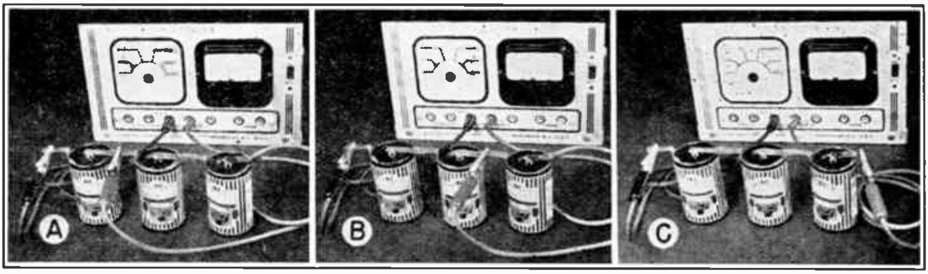


FIG. 10 These illustrations show you how to set up the three circuits in which you make current measurements as a part of Experiment 12. Note that the red probe is plugged into the +*I* jack, and the black probe is plugged into the −*I* jack. Leave the test probes in these jacks until you are told to 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 cases the resistance is so small that it can be neglected.

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	.6	.7	.75
3.0	1.25	1.6	1.50
4.5	2	2.3	2.25

TABLE 12. Record your results for Experiment 12 here

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 postwar "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

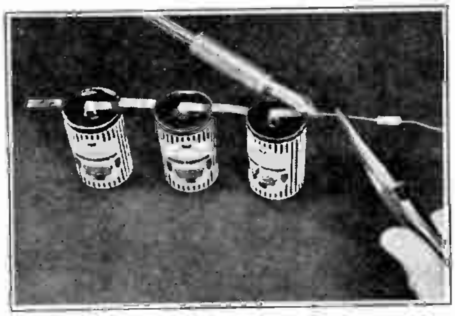


FIG. 11. To solder a resistor to a battery terminal strip by means of a lap joint, tin both the lead and the end of the strip, hold the resistor on the terminal strip with long-nose pliers as shown here, and apply the heated soldering iron.

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	2.3	2.25
	CURRENT THRU 900Ω AND METER (E = 4.5 V.)	1.4	1.6	1.55
2	CURRENT AT POINTS 8–9	1.4	1.6	1.55
	CURRENT AT POINTS 6–7	1.4	1.6	1.55
	CURRENT AT POINTS 4–5	1.4	1.6	1.55
	CURRENT AT POINTS 2–3	1.4	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

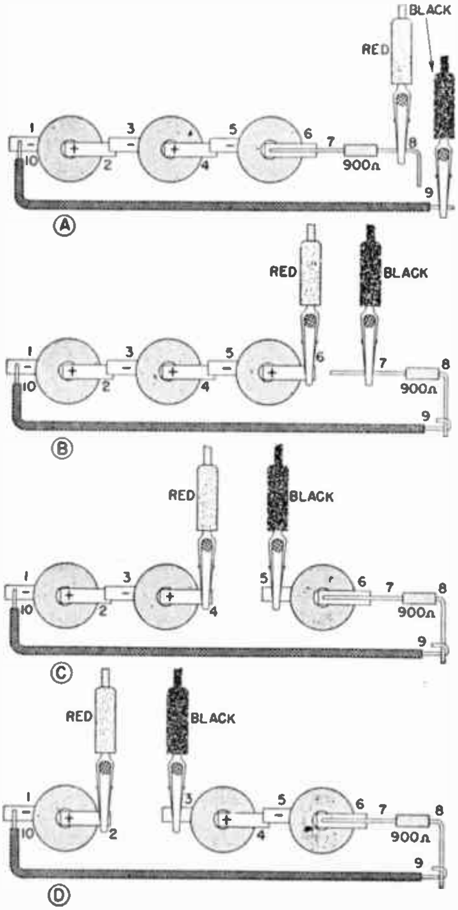


FIG. 12. Use these four milliammeter connections to prove for yourself that the same current value flows through all points in a series circuit.

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 place 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

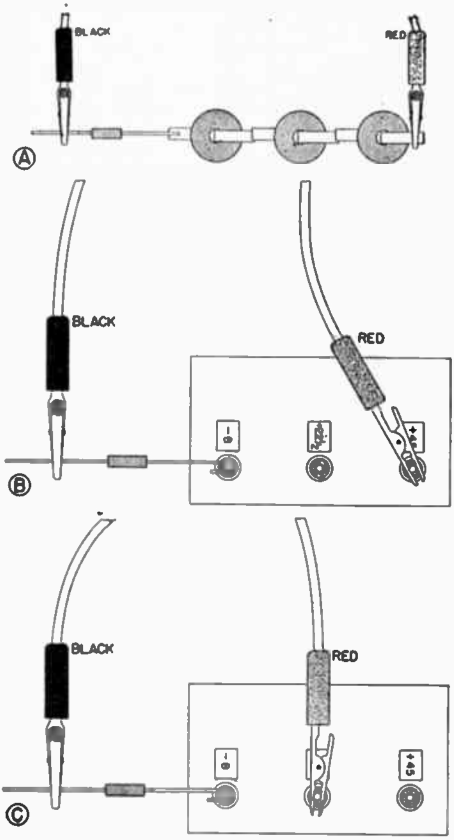


FIG. 13. The three circuits illustrated here all have the same total resistance (the meter with its resistance of 2,000 ohms is not shown, but is connected to the other ends of the two test leads in each case), but each circuit has a different voltage. In Experiment 14 you measure the current in each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

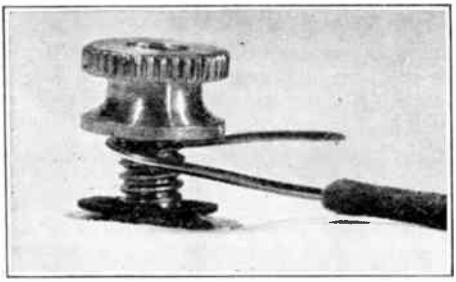


FIG. 14. Whenever you connect a wire or lead to a terminal screw, always bend the hook in a clockwise direction as shown here. This is the same direction in which you turn the nut when tightening it, and therefore the hook will tend to close rather than spread apart and come off when the nut is tightened. 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.*

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 = 4.5V.)	.245	.2	.225
2	CURRENT THRU 18,000Ω AND METER. (E = 45V.)	2.4	2.1	2.25
3	CURRENT THRU 18,000Ω AND METER. (E = 22.5V.)	1.20	1.0	1.13

TABLE 14. Record your results for Experiment 14 here.

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.

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.

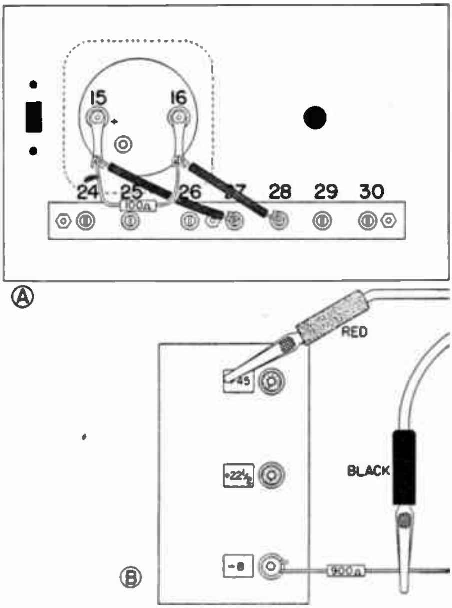


FIG. 15. By placing a 100-ohm shunt resistor across your meter in the manner shown at *A* here, you are able to measure (Experiment 15) the current in the circuit shown at *B*, even though this current is considerably higher than the 3-ma. maximum value which can be passed through the meter alone.

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

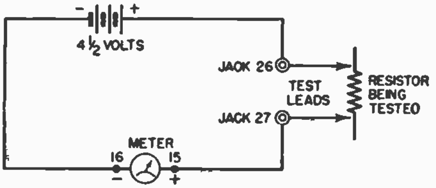
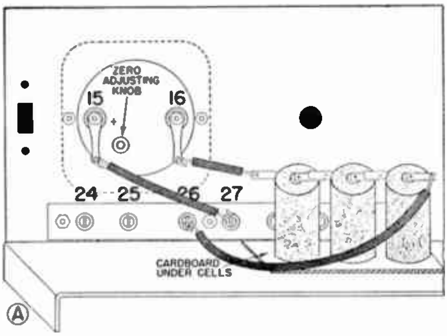


FIG. 16. Schematic circuit diagram for a series ohmmeter.

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



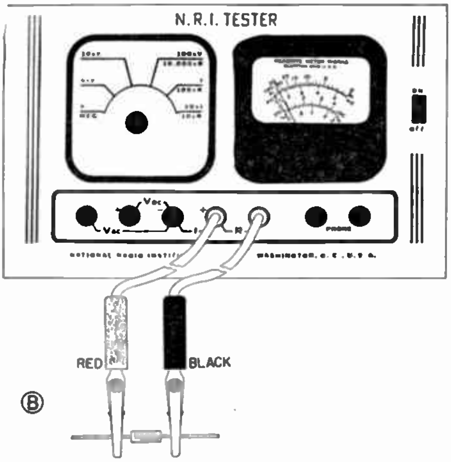


FIG. 17A (above). Rear view of panel, showing connections for the series ohmmeter which you set up in Step 1 of Experiment 16.

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.

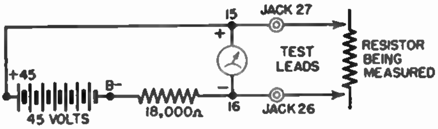


FIG. 18A. Schematic circuit diagram for a shunt ohmmeter.

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 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*.

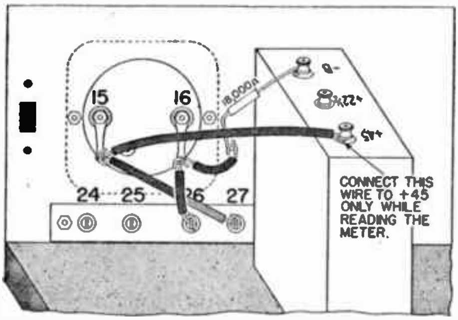


FIG. 18B. Rear view of panel, showing connections for the shunt ohmmeter which you set up in Step 2 of Experiment 16.

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 removing 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.

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	.175	.2	.225
	900	1.35	1.5	1.55
	100	1.75	2.2	2.14
	0	2.	2.3	2.25
2	900	.75	.7	.74
	100	.1	.1	.12
	0	0	0	0

TABLE 16. Record your results for Experiment 16 here.

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.*

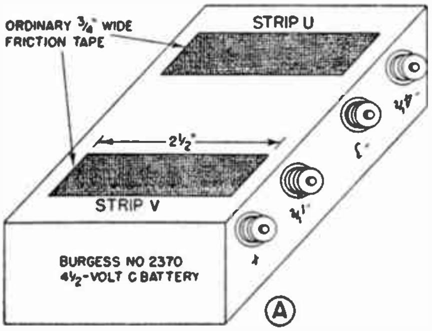
Experiment with different positions until you secure an arrangement which gives a compact group fitting within the battery tabs on the chassis, with all battery terminals at the top or facing the front panel so the terminals will be accessible and battery connecting leads will be as short as is practical.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

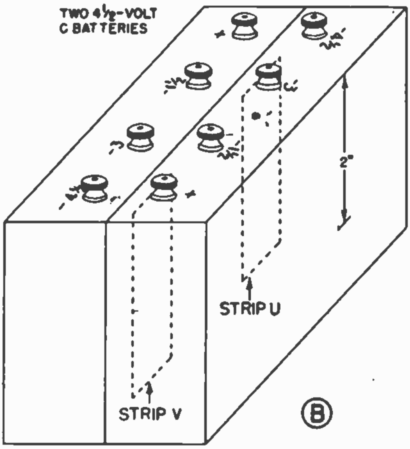
Step 2. Identify on top of the chassis with metal marking crayon the six holes which you previously marked *a*, *b*, *c*, *d*, *e* and *f* under the chassis. Do this carefully, one hole at a time, to make sure that each hole is marked the same above the chassis as it is below. These letters on top of 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*.





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.

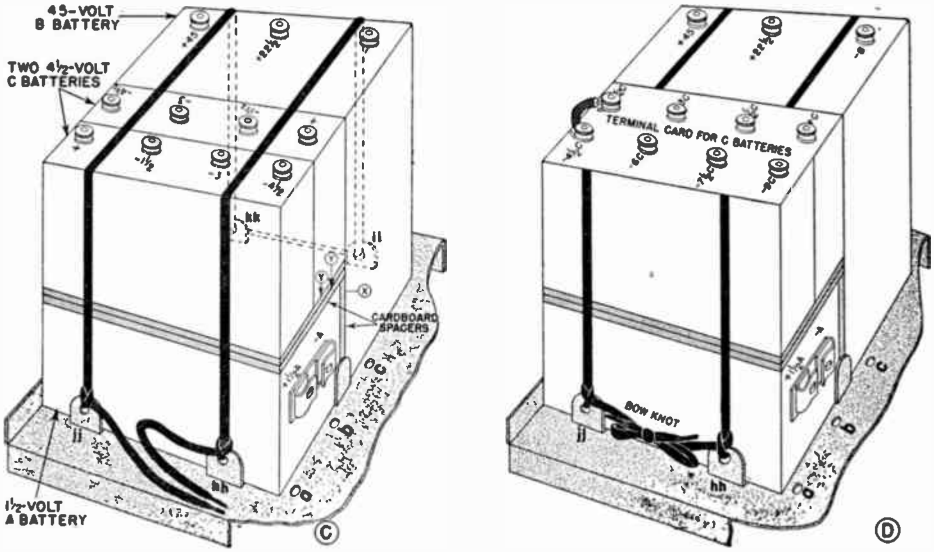
Note: For other battery makes, cardboard spacers may not be needed, or may have to be of different sizes. Bear in mind that spacers are used only to give a neat appearance to the battery group.

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.

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.

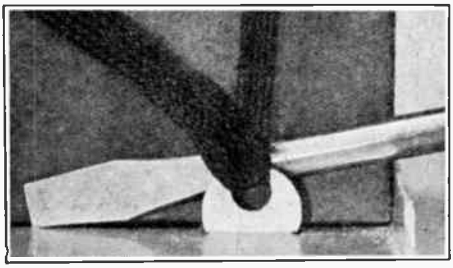


FIG. 19E. Method of holding the lace with a screwdriver while tying the final knot at battery tab *jj*.

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

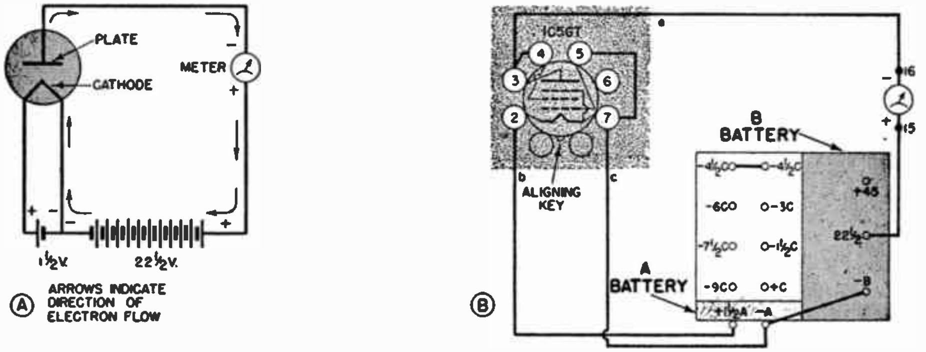


FIG. 20. Schematic circuit diagram *(A)* and semi-pictorial wiring diagram *(B)* for Step 1 of Experiment 17, in which you connect your type 1C5GT tube as a diode. The shaded area around the tube symbol in *B* indicates that connections to the tube socket are under the chassis. The letters e, b and c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

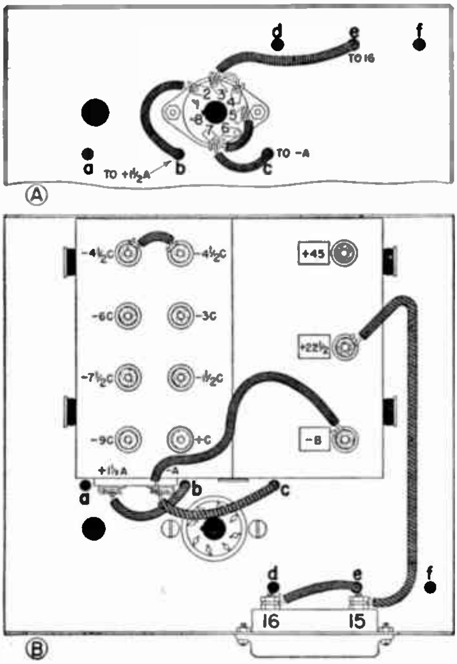


FIG. 21. Under-chassis *(A)* and above-chassis *(B)* connections for Step 1 of Experiment 17.

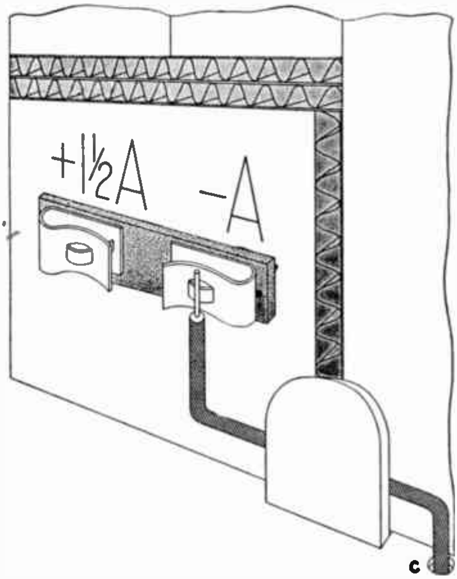
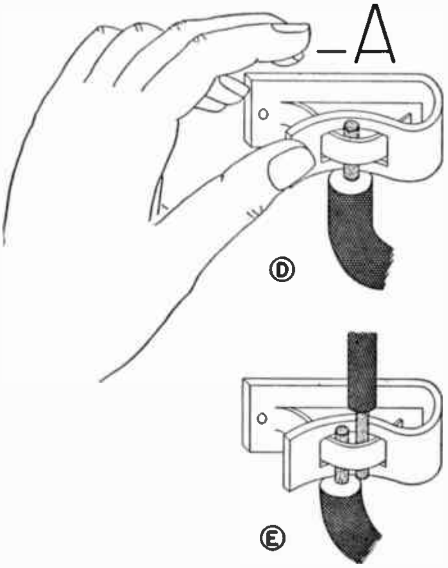


FIG. 21C. When two wires are to be inserted in a Fahnestock clip, bend the first wire so it will stay in this position by itself, before attempting to insert the wire in the clip.



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	1.75	2.2
2	SAME AS STEP 1, BUT WITH FILAMENT CIRCUIT OPEN	0	0
3	SAME AS STEP 1, 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 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*.

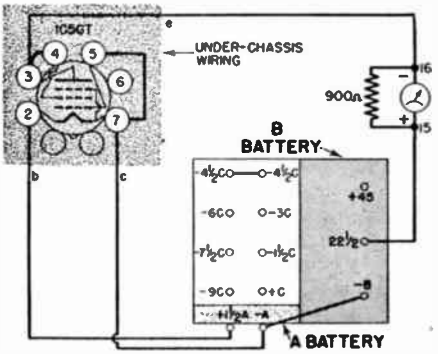


FIG. 22. Semi-pictorial wiring diagram for Step 1 of Experiment 18, in which you change the plate voltage on a diode tube from 22½ volts to 45 volts and note the effect upon plate current.

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

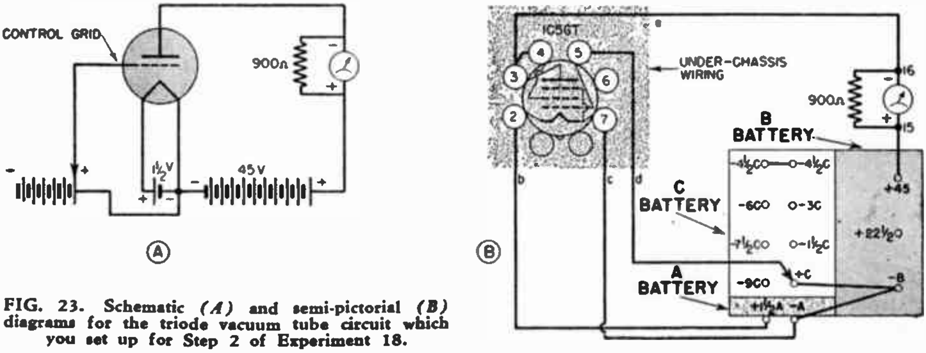


FIG. 23. Schematic *(A)* and semi-pictorial *(B)* diagrams for the triode vacuum tube circuit which you set up for Step 2 of Experiment 18.

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	.6	1.8	.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	–	.25	.75	.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

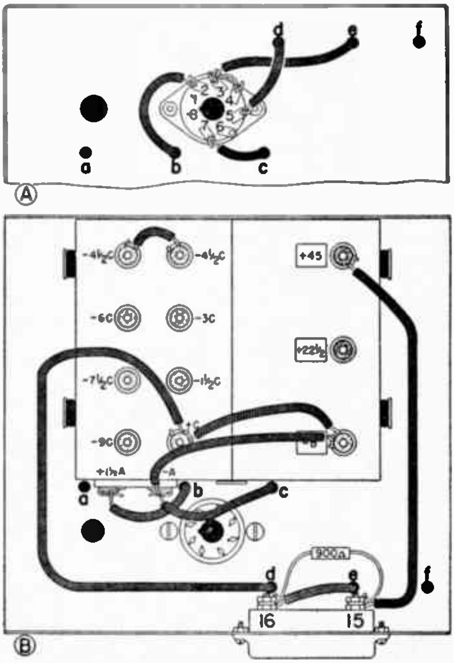


FIG. 24. Connections under the chassis for Step 2 in Experiment 18 should be as shown at *A*. The changes involved are as follows: Remove the lead which connects terminals 5 and 7, then bring a lead through hole *d* and connect it to terminal 5. Connections above the chassis should be changed to those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

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* 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.

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 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

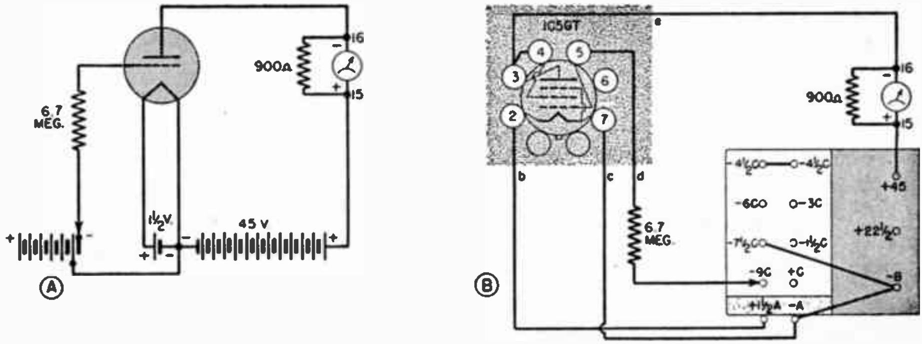

FIG. 25. Schematic *(A)* and semi-pictorial *(B)* diagrams for the triode vacuum tube circuit of Experiment 19. Note: Use the 6.8-megohm resistor sent you as Part 2-11 in place of the 6.7 meg. shown.

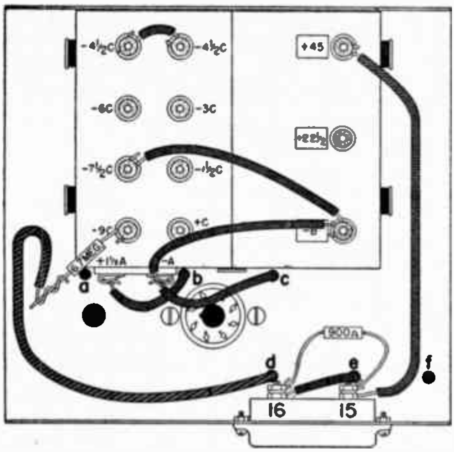

FIG. 26. Connections above the chassis should be modified to appear exactly as shown in this view, before starting to make measurements for Experiment 19.

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-

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	1.8	5.4	1.8	5.4
−1.5	0	1.6	4.8	1.8	5.4
0	6.7	2.4	7.5	2.5	7.5
0	0	2.5	2.5	2.5+	7.5+
+1.5	6.7	2.7	2.7	2.7	8.1
+1.5	0	3+	9+	3+	9+
+3	6.7	2.7	8.1	2.7	8.1
+4.5	6.7	2.7	8.7	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.

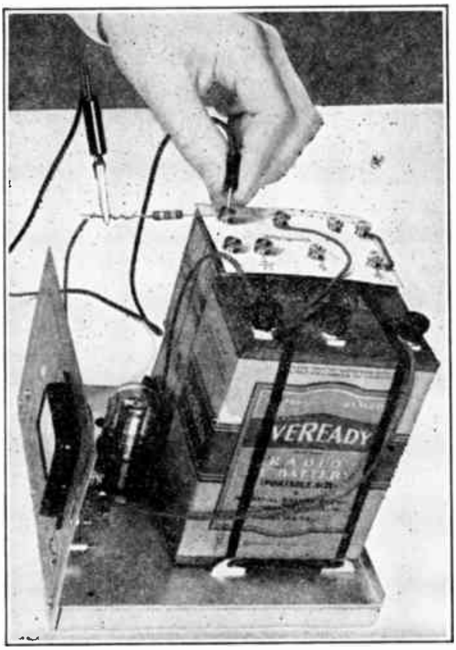

FIG. 27. Method of using a test lead to short out temporarily the grid resistor employed in Experiment 19.

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

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* 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.

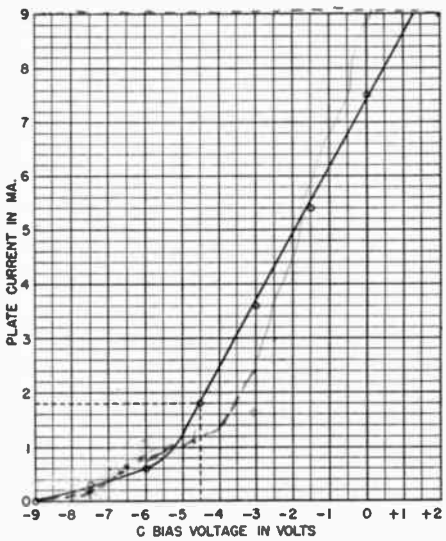
To secure a positive C bias voltage of 1.5 volts, remove from +C the lead which goes to —B, and connect this lead instead to —1½C, so —B and —1½C are now connected together. Leave the control grid lead on +C. Read the meter on scale I_M, and record your result in Table *20A* as the plate current for 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	0	0	0	0
-7.5	.1	.3	.1	.3
-6	.2	.6	.2	.6
-4.5	2.4	7.2	.6	1.8
-3	1.2	3.6	1.2	3.6
-1.5	1.7	5.1	1.8	5.4
0	2.5	7.5	2.5	7.5
+1.5	2.5	7.5	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.

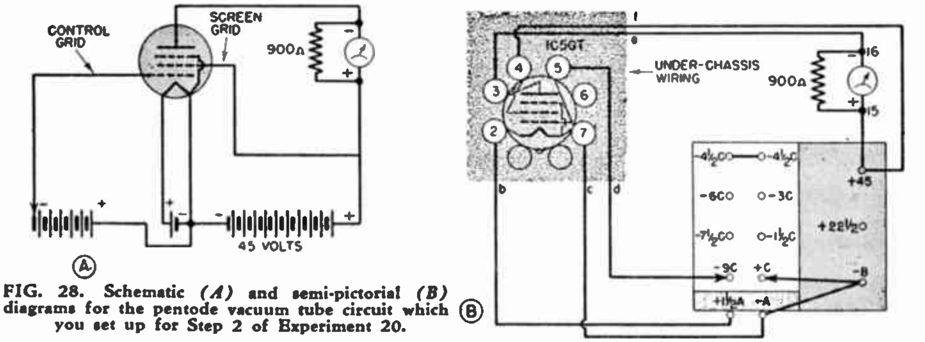


FIG. 28. Schematic *(A)* and semi-pictorial *(B)* diagrams for the pentode vacuum tube circuit which you set up for Step 2 of Experiment 20.

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

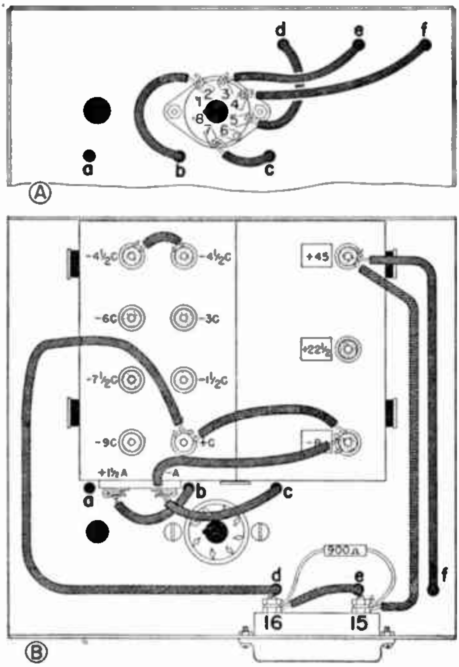


FIG. 29. Connections under the chassis for Step 2 of Experiment 20 should be as shown at *A*. Since the parts under the chassis are now wired according to Fig. *24*, simply remove the wire which connected terminals *3* and *4*, and run a wire through chassis hole *f* to terminal *4*. Battery connections 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.)

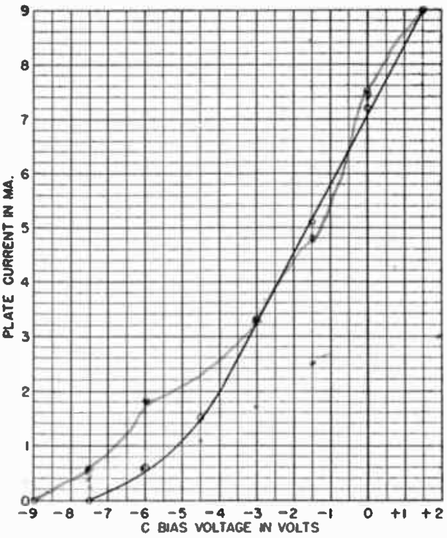
Move the control grid lead (coming through hole *d)* in turn to —7½C, —6C, —4½C, —3C, —1½C and +C; read the meter in each case and record your results in Table *20B*. The value marked on the battery terminal will be the C bias voltage in these cases, since the cathode is connected to +C.

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	0	0	0	0
-7.5	0	0	0	0
-6	.2	.6	.2	.6
-4.5	.6	1.8	.5	1.5
-3	1.1	3.3	1.1	3.3
-1.5	1.7	5.1	1.7	5.1
0	2.5	7.5	2.4	7.2
+1.5	2.7	8.1	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.

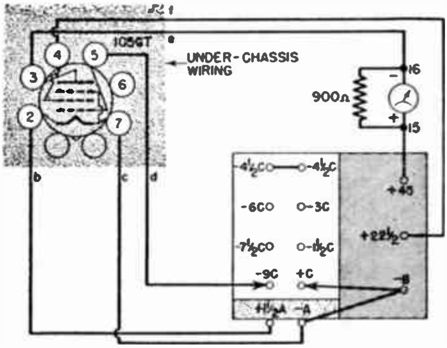


FIG. 30. Semi-pictorial wiring diagram showing all connections for Step 3 of Experiment 20. The only changes required to make your set-up coincide with this are moving of the screen grid lead (coming through hole *f)* from +45 to +22½, and returning to +C the lead coming from −B.

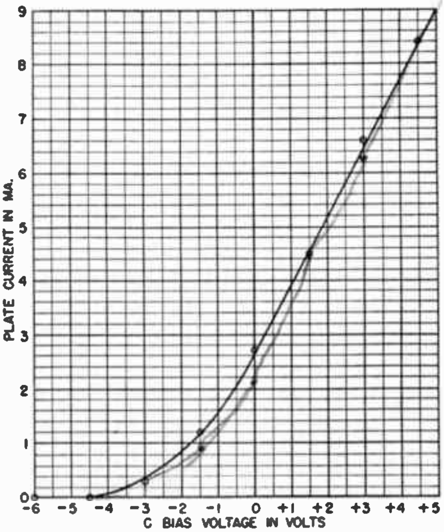
Graph *20B*, then draw a smooth curve passing through or near your points.

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.

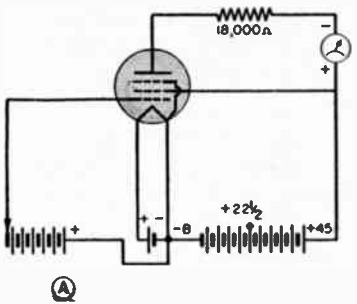
C BIAS VOLTAGE IN VOLTS	YOUR METER READING ON SCALE I_M	YOUR PLATE CURRENT IN MA.	N.R.I. METER READING ON SCALE I_M	N.R.I. PLATE CURRENT IN MA.
−9	+C 0	+C 1½ 3 0	0	0
−7.5	0	0	0	0
−6	0	0	0	0
−4.5	0	0	0	0
−3	.1	.3	.1	.3
−1.5	.3	.9	.4	1.2
0	.7	2.1	.9	2.7
+1.5	1.5	4.5	1.5	4.5
+3	2.1	6.3	2.2	6.6
+4.5	2.8	8.4	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.



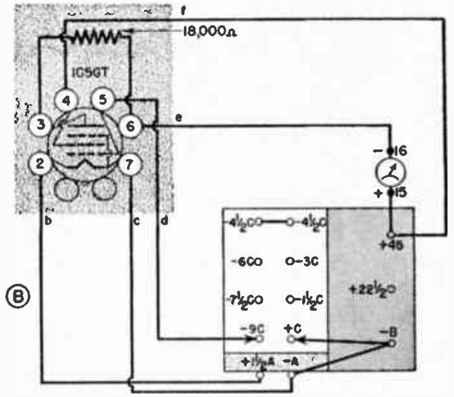


FIG. 31. Schematic *(A)* and semi-pictorial *(B)* diagrams for the circuit employed in Step 4 of Experiment 20.

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 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.

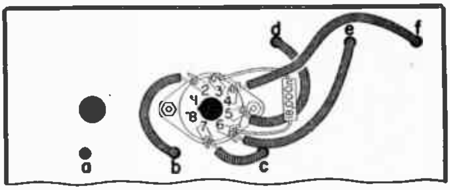


FIG. 32. Connections under the chassis for Step 4 of Experiment 20 should be as shown here. To make your circuit conform with this, move the plate lead (coming through hole *e)* from terminal 3 to terminal *6*, and connect an 18,000-ohm resistor between terminals *3* and *6*.

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

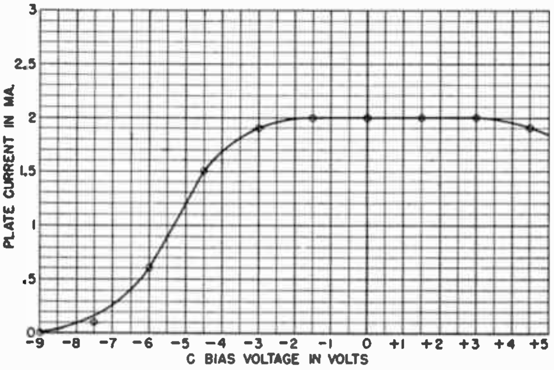
NRI laboratory. Our values and our curves are shown merely for comparison purposes and to illustrate the procedure for plotting this type of data on graphs. You can be sure your work is entirely satisfactory if you secure merely the same general shape or slant of curves, but remember that even this shape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



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.

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	0
-7.5	.1	.1
-6	.7	.6
-4.5	1.5	1.5
-3	2.0	1.9
-1.5	2.0	2
0	2.0	2
+1.5	2.0	2
+3	2.0	2
+4.5	1.9	1.9

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.

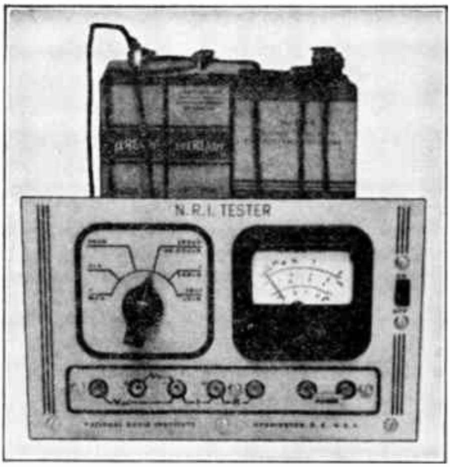


FIG. 33. Your NRI Tester should look like this after you have assembled it according to the simple step-by-step instructions in this manual, if you are using the specified Eveready batteries.

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.

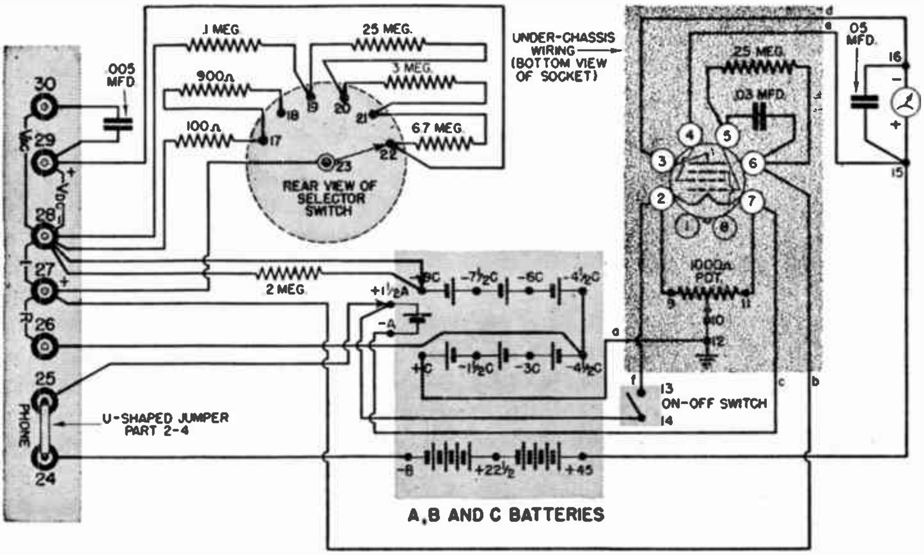


FIG. 34. Circuit diagram of the NRI Tester. This is presented here for reference and checking purposes: you will follow pictorial diagrams and photographs when assembling the unit, to minimize chances for errors. Note: The 6.7, .25, and .2-megohm resistors, and the 900-ohm resistor, shown above have 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 panel). Be careful not to let the pliers slip and scratch the panel.

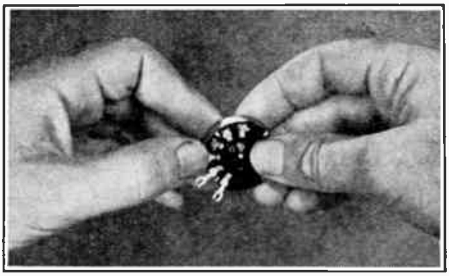


FIG. 35. Method of bending out the soldering lugs on the rotary selector switch (Part *2-6*). Press them outward with your thumb, one at a time, until all the outer lugs point outward like the spokes of a wheel. Do not bend the single center lug.

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

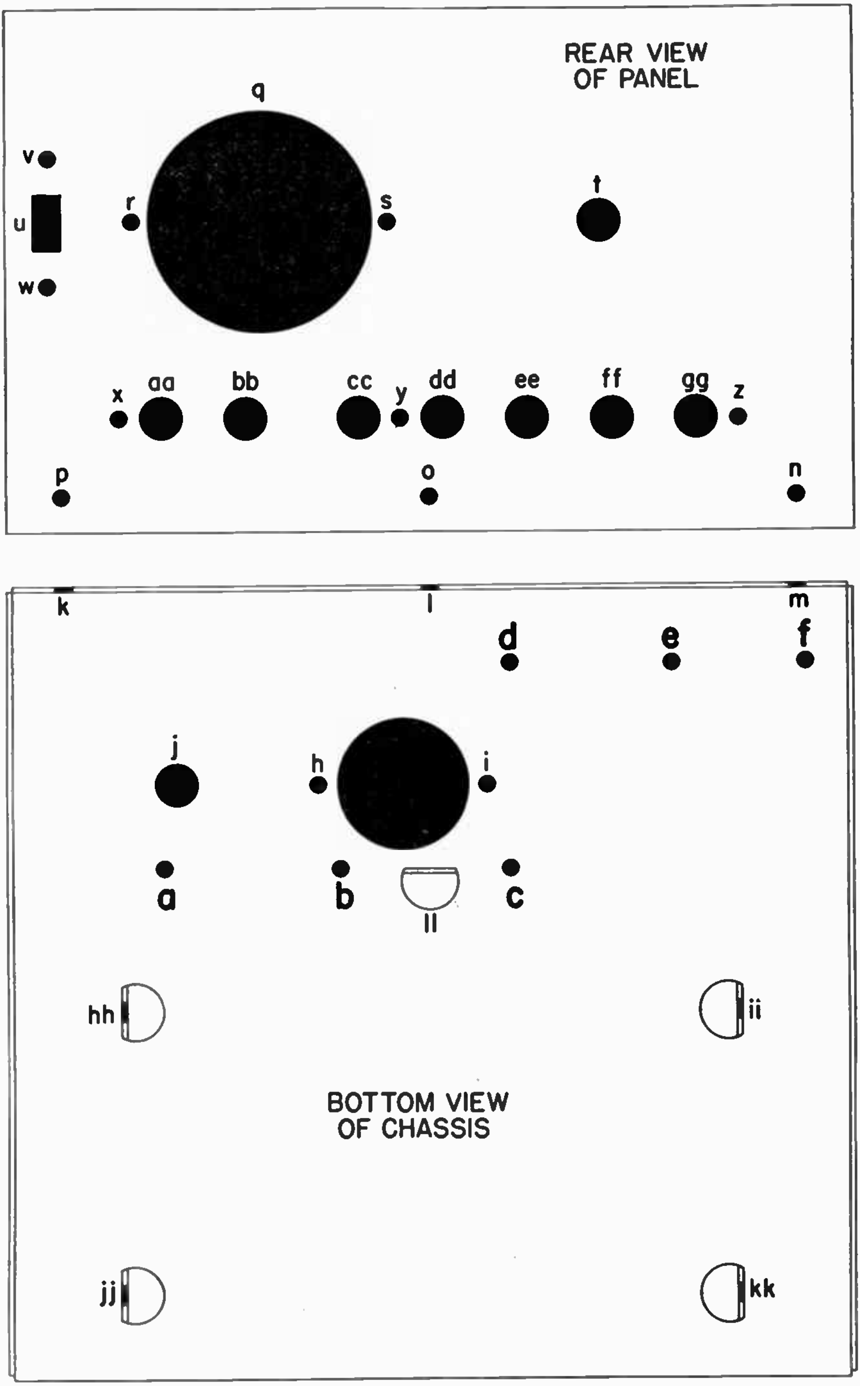


FIG. 36. Rear view of tester panel (above) and bottom view of chassis (below), with all holes identified by letters for convenience in referring to them. The only letters which are to be marked on your parts, however, are those identifying chassis holes, *a*, *b*, *c*, *d*, *e* and *f*. Use these diagrams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

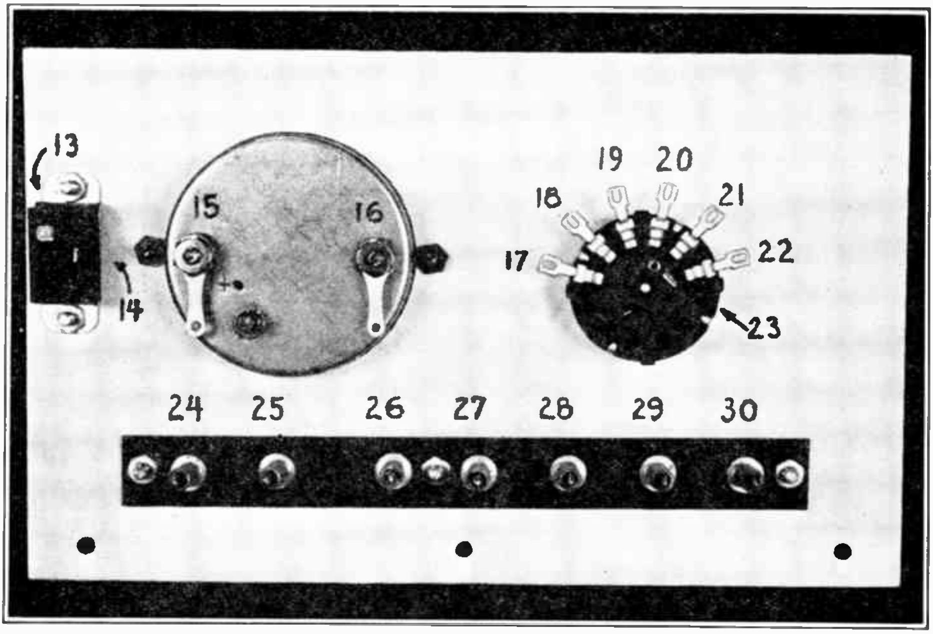


FIG. 37. The back of your tester panel should appear like this after you have mounted the selector switch and ON-OFF switch, as instructed in Steps 2 and 3. (The meter and jack strip were mounted as part of Experiment 11.) Number the various terminals on your own panel by marking them with crayon or 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

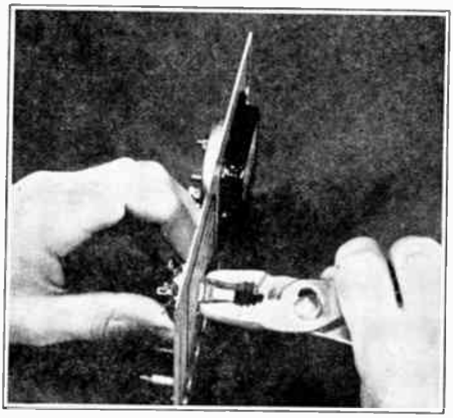


FIG. 38. Method of using ordinary pliers to tighten the nut on the rotary selector switch. Use the same technique for tightening the nut on the 1,000-ohm potentiometer.

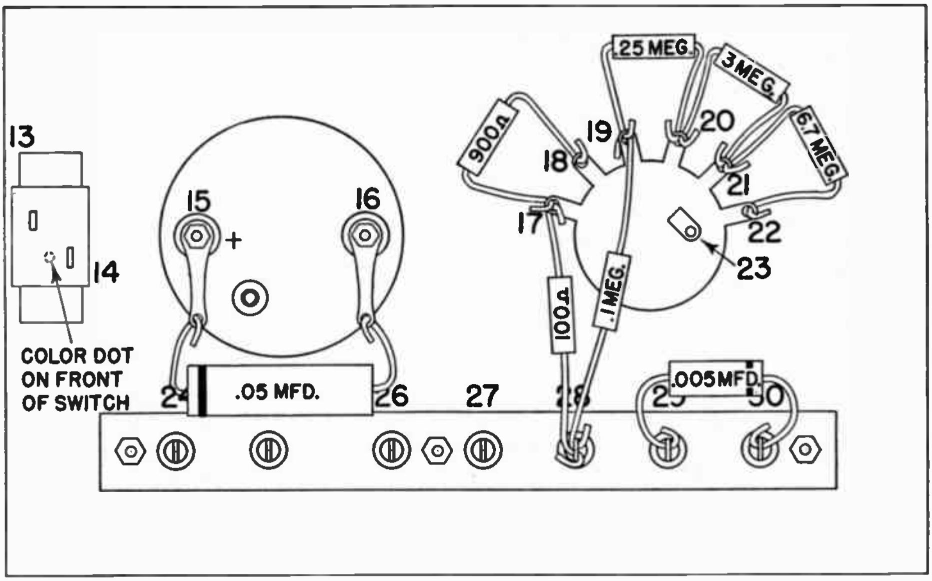


FIG. 39. Rear view of front panel, showing positions of all condensers and resistors. No soldered joints have been made yet. All hook joints should be closed when instructions for this are given in the text.

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

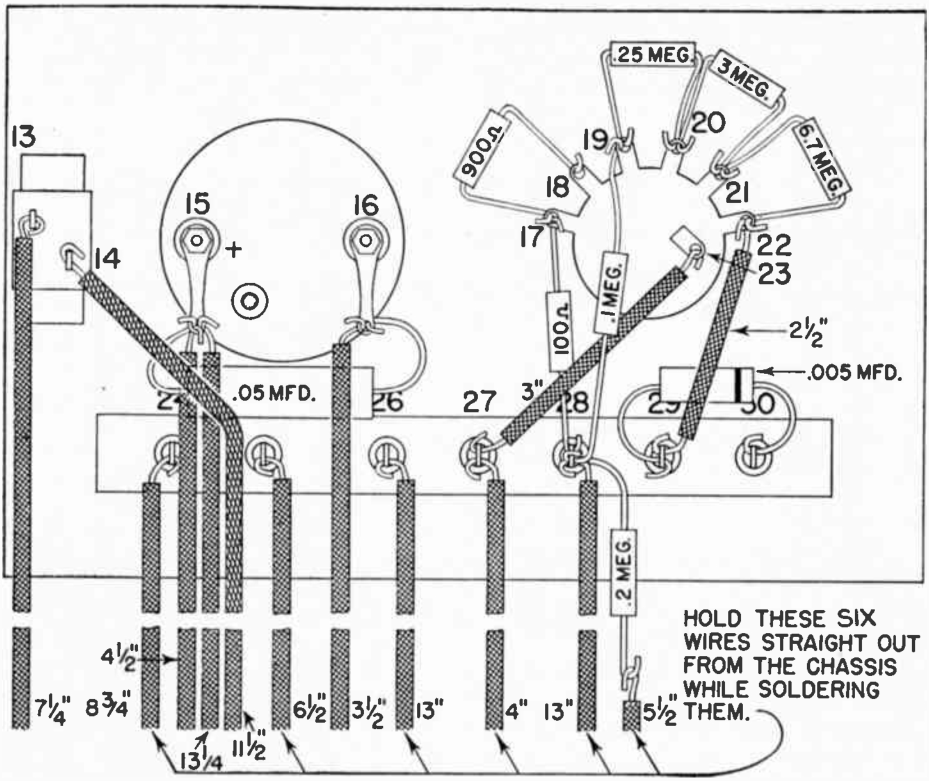


FIG. 40. Rear view of front panel after all leads and parts have been connected with permanent soldered hook joints. The length in inches to which you should cut each piece of hook-up wire is indicated alongside the wire. To save space in this manual and to simplify this diagram, the long leads are shown 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-

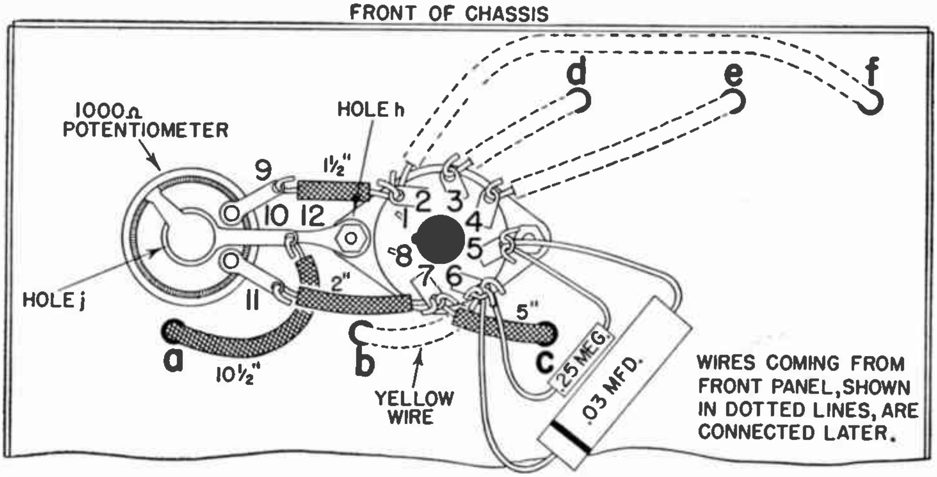


FIG. 41. Bottom view of chassis, showing preliminary assembly of leads and wires. After the chassis is bolted to the panel, four wires from the panel will be run through holes *b, d, e* and *f* and connected to terminals *6, 3, 4* and *2,* respectively, as indicated by the dotted lines.

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 10½-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 10½-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 1½-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 ¾-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 1¼-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

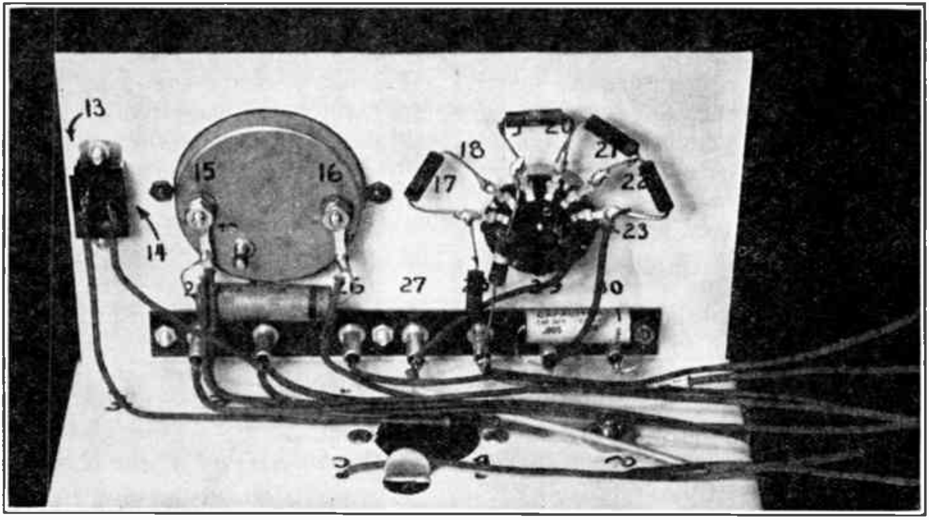


FIG. 42. Rear view of NRI Tester after the panel is fastened to the chassis. Note that the leads have been temporarily bent off the chassis to the right to permit placing the battery block on the chassis between the five tabs. The position of the *OUTSIDE FOIL* lead of the condenser connected between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

condenser are both self-supporting about ⅛-inch away from the metal chassis.

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 4½-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 3½-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

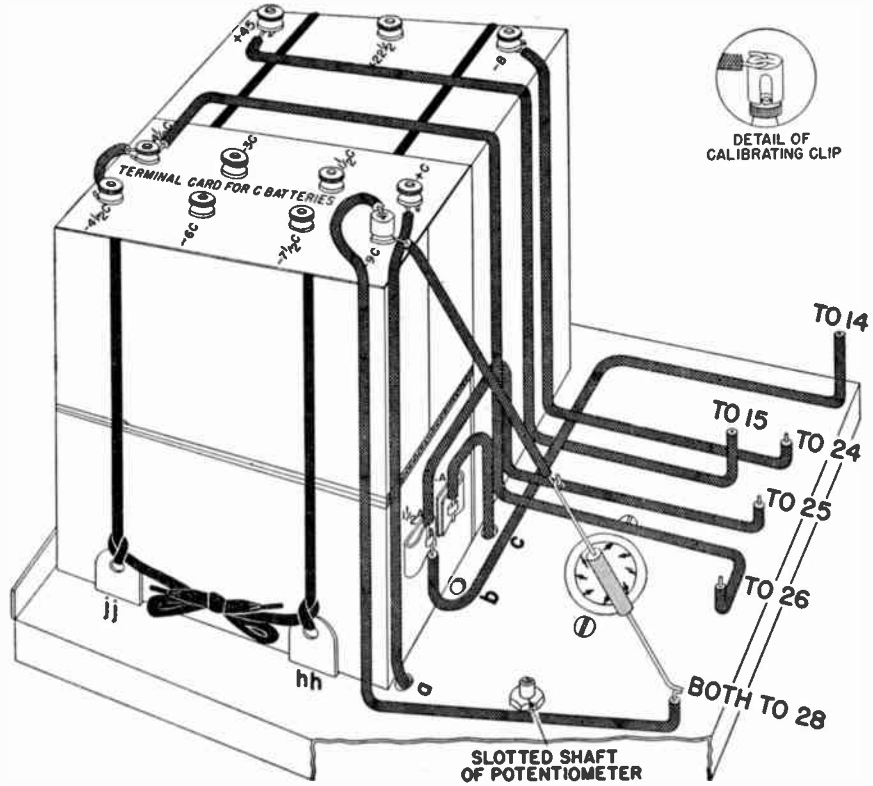


FIG. 43. **Battery connections for the NRI Tester when using the specified Eveready batteries.**
WARNING: DO NOT LET METER TERMINAL *15* OR THE +45 TERMINAL OF THE BATTERY COME IN CONTACT WITH THE CHASSIS OR WITH ANY OTHER BATTERY TERMINAL, BECAUSE AN ACCIDENTAL CONNECTION OF THIS NATURE MAY BURN OUT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

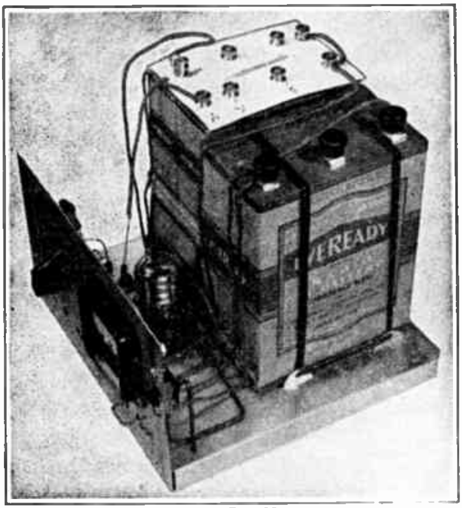


FIG. 44. Completed NRI Tester, as it appears when the specified Eveready batteries are used.

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 +1½*A*. To do this, remove from the +1½*A* 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 +1½*A*. 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.*

INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 1 TO 10

1 RK-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

A COURSE IN PRACTICAL DEMONSTRATIONS OF RADIO FUNDAMENTALS

A PLAN FOR STUDYING THE EXPERIMENTS

As you know, these Experimental Kits will come to you on a definite schedule. When you have completed a certain number of Lessons (and have submitted reports on any previous experiments), the next Kit will be sent to you.

This arrangement is such that you will study the necessary theory in your regular Lessons *before* you carry out any corresponding experiments. This permits you to adopt either of the following plans of study:

1. You may wish to complete one or two experiments in a Kit, then do a Lesson, and then return to the Kit for one or two more experiments. This plan permits the experiments in one Kit to be finished about the time the next Kit is due. Thus, the Lessons and experiments run along together, and provide you with a varied program of study.
2. You may prefer to break away from your Lessons and to complete all the experiments in a Kit at one time, before going back to your Lessons. This plan has the advantage that you do not waste any time getting out and putting away materials, but it can be followed only if you can leave your equipment set up long enough to finish.

Whichever plan you follow, you can begin NOW with the experiments in this Kit. Be sure to read the preliminary information on pages one through ten *before* you begin, however, so you will know just how the experiments are to be carried out. In a similar manner, begin on future Kits as soon as you receive them.

J. A. Dowie.

NATIONAL RADIO INSTITUTE
WASHINGTON, D. C.

1949 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NPC10M1149

Printed in U. S. A.

Instructions for Performing Radio Experiments 1 to 10

Bringing Lecture Room Demonstrations to Your Home

MASTERY of an important radio or electrical principle which you study in your NRI Course becomes much easier if you can actually demonstrate that principle for yourself. Seeing is believing; when you carry out an experiment, you impress indelibly upon your mind the principle involved.

The NRI Course of training in radio is a well-balanced combination of radio theory and practical instruction, *supplemented by the practical demonstrations* given in this and the following experimental Manuals. By doing these experiments yourself, you get actual experience in handling radio parts and making radio measurements, and you acquire the ability to understand explanations of more advanced circuit actions. This experience *is even more valuable to you* than demonstrations by an instructor in a lecture room.

These practical NRI radio experiments will develop confidence in your own ability, and will provide exactly what you need to develop yourself into a practical radio technician—a real *Radiotrician and Teletrician.* You will encounter and master technical problems, one by one. You will learn to connect radio parts together in a professional manner. You will see for yourself what happens when a particular part in a radio circuit is removed or made defective. You will learn how to detect and correct errors in connecting parts together, and how to adjust and align practical radio circuits.

Every single experiment is important, so do not pass over any one of them hurriedly even though you may already know what the results will be.

Importance of Mastering the Art of Soldering

If you examine the chassis of any modern radio receiver or public address amplifier, you will find that the parts are connected together by means of soldered connections. These are the most reliable connections it is possible to make in commercial production; a good soldered connection will not deteriorate appreciably during the entire life of a piece of radio equipment.

When repairing a defective receiver, you must first locate the defective part. But the ability to determine what is wrong with a radio device is of little value unless you also know how to remove the defective part and how to solder the connections for the new part. Furthermore, it will often be necessary to *unsolder* one or more connections in order to make tests which will reveal the defective part.

This first Manual in your Practical Demonstration Course is devoted entirely to soldering. You study the fundamentals of radio soldering, then learn how to make each of the common types of soldered connections used in radio work. The soldering iron, solder, hook-up wire, and radio parts included with this Radio Kit for these first ten experiments are all standard, just like those you would work with when servicing.

Contents of This Radio Kit

The parts included in your first Radio Kit are illustrated in Fig. *1*

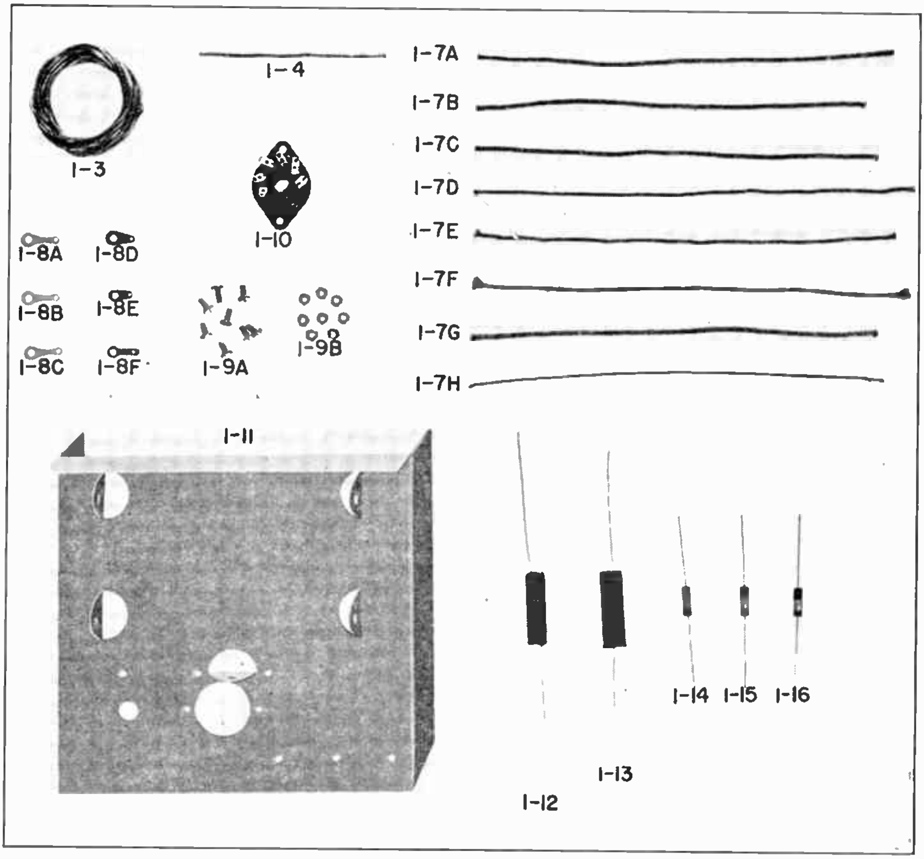


FIG. 1. The parts included in this Radio Kit are pictured above, and identified in the list below. The first numeral in a part number is that of the Kit in which the part is supplied; thus, parts supplied in the second Radio Kit will be numbered *2-1, 2-2,* etc., and parts supplied in the third Kit will be numbered *3-1, 3-2,* etc. With this system, you can tell at a glance the number of the Kit in which a particular part was supplied.

PART NO.	DESCRIPTION
1-1	One electric soldering iron (not shown above).*
1-3	One roll of rosin-core solder.
1-4	One 3-inch length of plain solder.
1-7A	One 8-inch length of No. 20 *solid* tinned push-back wire.
1-7B	One 8-inch length of No. 20 *solid* tinned push-back wire.
1-7C	One 8-inch length of No. 20 *solid* tinned push-back wire. (Parts *1-7A, 1-7B, and 1-7C* are identical, and are numbered differently merely for convenience.)
1-7D	One 8-inch length of No. 20 *stranded* tinned push-back wire.
1-7E	One 8-inch length of No. 18 solid *untinned* insulated wire.
1-7F	One 8-inch length of No. 20 stranded tinned wire with glazed insulation.
1-7G	One 8-inch length of No. 18 stranded untinned lamp cord.
1-7H	One 8-inch length of 7-strand No. 26 enameled aerial wire.
1-8A	One 13/16-inch tinned soldering lug.
1-8B	One 13/16-inch tinned soldering lug.
1-8C	One 13/16-inch tinned soldering lug. (Parts *1-8A, 1-8B,* and *1-8C* are identical, and are numbered differently merely for convenience.)
1-8D	One 5/8-inch untinned soldering lug.
1-8E	One 1/2-inch untinned soldering lug.
1-8F	One 11/16-inch untinned soldering lug.
1-9A	Eight ¼-inch long, 6-32 cadmium-plated binder-head machine screws.
1-9B	Eight cadmium-plated hexagonal nuts for 6-32 screws.
1-10	One octal-type tube socket with six terminal lugs. (Slots 2, 3, 4, 5, 6, and 7 should have lugs, as shown in Figs. *39* and *40.* Some lugs may seem loose, but they will tighten automatically when a tube is plugged into the socket.)
1-11	One metal chassis bent to shape, with all holes already punched out for future use.
1-12	One .03-mfd., 400-volt tubular paper condenser.
1-13	One .05-mfd., 400-volt tubular paper condenser.
1-14	One .24-megohm, 1/2-watt resistor with 5% tolerance (color-coded red, yellow, yellow gold).
1-15	One .1-megohm, ½-watt resistor with 5% tolerance (color-coded brown, black, yellow, gold).
1-16	One 18,000-ohm, ½-watt resistor with 10% tolerance (color-coded brown, gray, orange, silver).
1-17	One metal-marking crayon (not shown above).

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* If you have previously notified the Institute that you do not have 115-volt power available, Part *1-1* will be missing. In its place you will receive Part *1-1A,* a plain soldering iron of the same general construction as the one illustrated in Fig *6.*

and listed in the caption underneath. Check off on this list the parts which you received, to be sure you have all of them. Do not destroy any of these parts until you have completed your NRI Course, for many of the parts will be used over and over again in later experiments.

IMPORTANT: If any part in this Radio Kit is obviously defective or has been damaged during shipment, please return *the defective part* to the Institute *immediately* for replacement.

Tools Needed

For the experiments in your Practical Demonstration Course, you will need the tools which are shown in Fig. 2 and listed in the caption underneath. These tools are *not* supplied in this Radio Kit. You undoubtedly have at least some of them already since they are common home tools. Those which you do not have are readily obtainable at local hardware stores, dime stores, mail-order firms, or radio-supply firms. All of the tools will be needed for radio servicing work and for later experiments in your Practical Demonstration Course, so they are a really worthwhile investment.

Theory of Soldering

Any art or technique is easier to master if you first study the fundamental principles and theories which are involved. For this reason, we will consider now what solder actually is, why it adheres to certain metals under certain conditions, and why solder is so essential for permanent connections in radio circuits.

Molecular Attraction. When two ordinary solid objects are pressed together, nothing happens. Thus, we cannot make a block of solder stick to a block of copper merely by pressing the two blocks together.

It is possible to grind two metal surfaces so perfectly flat and smooth that they will adhere to each other when pressed together with a twisting force. The Johansson gage blocks used by machinists for precision measurements are an example of this phenomenon. When these blocks are pressed together hard enough to force air out from between the adjoining surfaces, the molecules of steel get close enough to attract each other with tremendous force. *Molecular attraction* thus explains why Johansson gage blocks stick together.

Why Solder Adheres. In soldering, it is unnecessary to have perfectly flat surfaces on the objects which are to be joined together. When both metal objects, even though irregular, are made perfectly clean (free of foreign materials such as chemical oxides, grease, and dirt) and are heated to the proper temperature, molten solder will adhere to the two cleaned surfaces and will bridge the gaps between them. Now, when the solder has cooled and hardened, its surface molecules will be just as close to the molecules in the adjoining cleaned but irregular surfaces as are the molecules in gage blocks. *Molecular attraction* thus makes solder adhere to certain metals.

Once a metallic surface has been *tinned* by making a layer of solder adhere to it, additional solder can very easily be *fused* to that already on the metal. (Two pieces of solder can be combined or fused simply by placing one in contact with the other and applying heat.)

What Solder Is. Solder is a *fusible metal or alloy of metals which is used to provide a good bond between two or more metal objects.* Solder used for radio work contains only

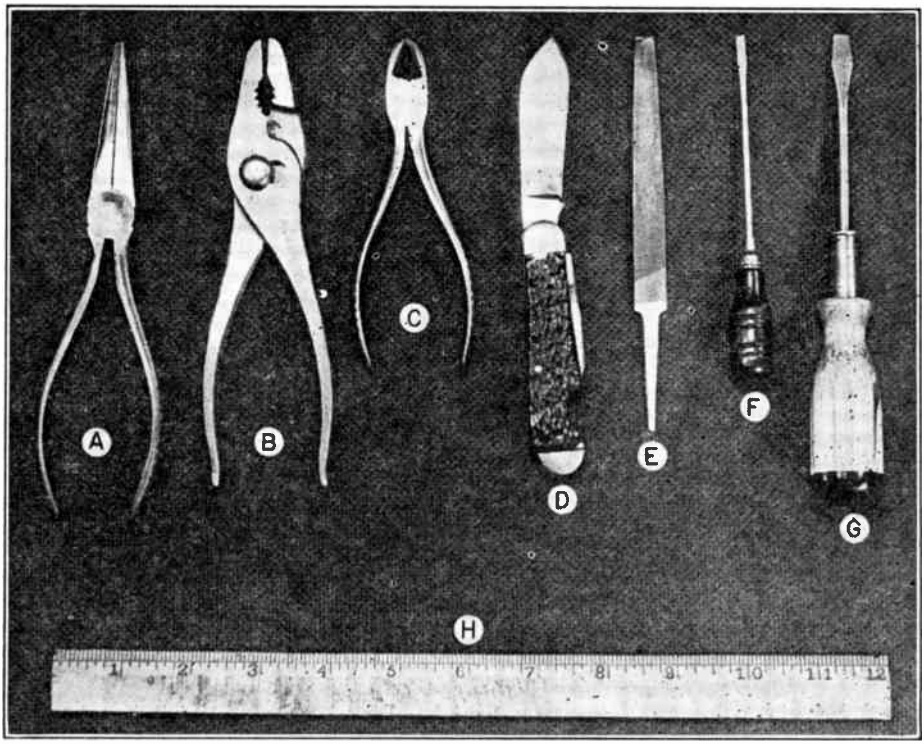


FIG. 2. The essential tools which you will need for the experiments in your Practical Demonstration Course are pictured here and identified below. Get the best diagonal cutting pliers and long-nose pliers you can afford, for you will use these tools continually throughout your Practical Demonstration Course and in actual radio work of all kinds.

A—One pair long-nose pliers (5 to 7 inches long). These may have wire-cutting jaws, but this feature is not essential.
B—One pair ordinary all-purpose pliers (6 to 7 inches long).
C—One pair diagonal cutting pliers (5 to 6 inches long).
D—One ordinary pocket knife (jack-knife).
E—One medium-size flat metal-cutting file (about 7 inches long).
F—One small screwdriver (about 5 inches long).
G—One medium-size screwdriver (about 7 inches long).
H—One 12-inch ruler of any type.

lead and tin. The ratio of lead to tin determines the hardness, strength, and melting point of the solder.

Radio solder will adhere to iron, steel, brass, copper, cadmium, and phosphor bronze when these metals are properly cleaned. Radio men have no need for soldering to aluminum, which requires a special aluminum solder.

Importance of Heating the Work. Solder will *not* adhere to a metal surface unless that metal surface is perfectly clean. Furthermore, *molten solder will not adhere to a cold surface.* To solder successfully, you must *heat the work to a temperature that will melt the solder into a smooth flowing liquid when it is applied directly to the work.* If you fail to melt the solder to a liquid, you will get a "cold" joint that will be no good at all.

It is also essential that you apply the heat for a sufficient length of time to burn *all* the rosin flux out of the joint. If you fail to do this, you will get what radio men call a "rosin joint" which introduces unnecessary resistance into the circuit.

Soldering Irons

All types of soldering irons have a pointed tip made of copper or some suitable alloy of copper, a handle (usually made of wood), and a hollow metal tube, or some other suitable means of joining the handle and tip. The pointed tip is heated and applied to the work. Heat is transferred from the tip to the work, which quickly becomes hot enough to melt the solder. Soldering irons differ principally in the methods used to heat the pointed tip—some having the tip heated continuously by an electric current, others requiring an open flame.

Electric Soldering Irons. Electrically heated soldering irons like those shown in Fig. *3* are used more than any other type by the radio industry. The various makes differ in size and shape, but their essential construction is the same. Some have the pointed rod completely surrounded by the heating element; others have the heating element fitted inside the soldering tip.

At the other end of the hollow metal tube is a wooden handle. The line cord passes through the wooden handle and the hollow metal tube, and connects to the terminals of the heating element. The heating element itself consists of nichrome resistance wire (like that used in electric stoves) wound into a coil and covered by a heat-resistant insulating material.

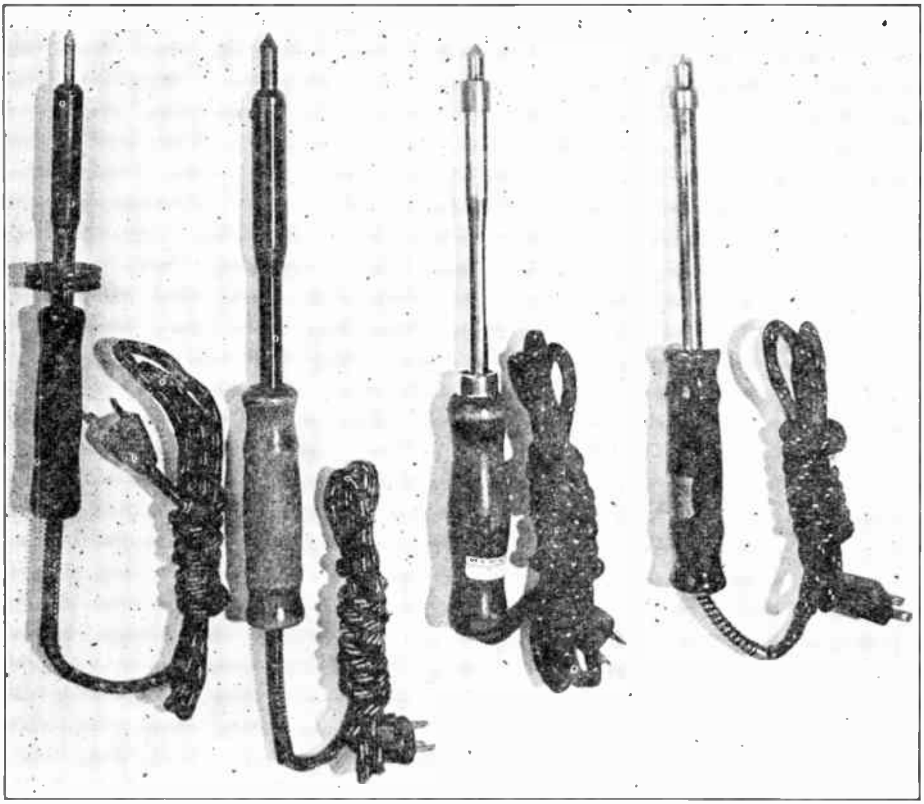


FIG. 3. These are the types of electric soldering irons most frequently used in radio work. The soldering iron (Part *1-1*) we supply in this Kit may or may not look like one of these, depending upon what we can obtain when we pack the Kit.

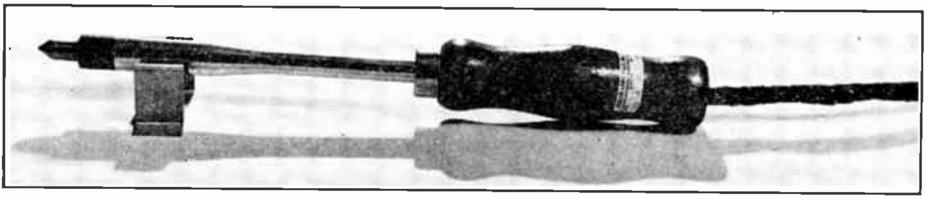


FIG. 4. This shows how to place your soldering iron on a metal holder. Note that the working tip is placed beyond the holder, so that it does not become cooler through contact with the metal which would carry off some of its heat.

Never unscrew the copper tip of the NRI electric soldering iron; the heating element inside is fragile, and is easily damaged when exposed. If the copper tip becomes loose during normal use, tighten it while the iron is cold. Do not drop your soldering iron or swing it carelessly against a hard object; more important yet, *never use your soldering iron as a hammer,* for that will surely damage the heating element.

Electric soldering irons are usually built for 115-volt operation,* and can be used with either a.c. or d.c. power. For ordinary radio servicing work, the heating element should have a wattage rating of from 50 to 60 watts. Allow about three minutes for the NRI iron to heat up after plugging it into a power source.

Purpose of Soldering Iron Holder. A heated soldering iron should always be returned to its metal holder when not in use. Fig. *4* shows a convenient holder and how to place the soldering iron on it. It is best not to let the hot copper portion touch the holder. The tip end of the barrel is the hottest part of the iron; heat conducted from the barrel through the metal holder may scorch the workbench or other surface on which the holder is resting, and heat conducted away from the barrel by the holder will tend to cool the tip.

The soldering iron holder should be kept conveniently close to your work, but never in a position where you might accidentally knock the iron out of the holder. A heated soldering iron is hot enough to do considerable damage to your hands, to your clothes, or to wooden table tops, so be careful.

Heat Controls. If the full rated voltage is applied to an electric soldering iron for long periods of time during which the iron is not used, the tip will become covered by a hard black substance (copper oxide) that will make it useless for soldering. The reason for this is that copper is a metal that oxidizes rapidly, especially when heated to the high temperatures required for good soldering. If you wish to plug your soldering iron in when you start your experimental work, and leave the iron plugged in until you are through for the day, you should form the habit of wiping the tip frequently with a cloth or piece of steel wool, to keep the oxide from forming.

You may, however, find it more convenient to use one of the heat controls shown in Fig. *5*. The control shown at *A* in Fig. *5* is a commercially manufactured unit having a thermostat that can be adjusted for any desired temperature. As long as the soldering iron is kept on this special stand, the thermostat in the base of

---

*Power-line voltages may vary between 110 volts and 120 volts. Up to a few years ago, line voltages at homes were around 110 volts, but today most homes have voltages approaching 120 volts. An electric soldering iron built for 115-volt operation can be used on any voltage between 110 volts and 125 volts.

FIG. 5. A commercially manufactured heat control of the thermostat type is shown at A; one you can build yourself is shown at B.

the stand maintains the tip of the iron at the desired temperature. As soon as the iron is removed from the stand, full rated voltage is applied to the heating element, and the tip quickly reaches operating temperature.

The device shown at *B* in Fig. *5* is a thoroughly practical heat control, which you can build yourself. The wattage rating of the lamp bulb depends on the wattage rating of the iron, and should be chosen so that when the switch is *open,* the voltage applied to the iron will be between 80 and 90 volts. When the switch is open, the lamp and heating element of the iron are in series, and the iron operates at reduced voltage. This will keep the tip from oxidizing so quickly. Shortly before the iron is to be used, the switch is closed, and full voltage is applied to the iron, bringing the tip to operating temperature. Note that the switch is connected *in parallel*

with the lamp; not in series with the supply line.

Plain Soldering Iron. When electric power is not available, a plain soldering iron similar to the one shown in Fig. *6* may be used. This type of soldering iron is heated by placing the copper tip in the flame of an alcohol burner or gasoline blow torch. Once heated to the proper temperature, a plain soldering iron holds its heat long enough to make a number of soldered joints. It is then reheated for additional work.

In an emergency, you can heat the copper tip of any electric soldering iron in the flame of an alcohol burner. Radiotricians who get occasional calls from suburban or rural homes not equipped with electricity often carry

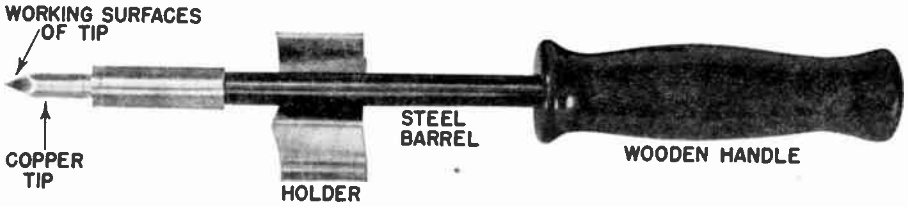


FIG. 6. This is called a plain soldering iron, as its working tip is heated in a flame. It is used where no electric power is available. A suitable heating device is described in the text.

along in their tool kit a can of special heating fuel called "canned heat," or an alcohol burner like that described later in this Manual.

Soldering Flux

When plain solder is applied to a heated piece of uncleaned brass or copper, the solder melts but rolls off immediately, without adhering. This is to be expected, for ordinary uncleaned metal is covered with a film of grease, dirt, and metal oxides which prevent the molecules of solder from getting sufficiently close to the molecules of brass or copper. Filing the surface of the brass or copper makes it appear clean, but ordinarily does little good because oxides form very rapidly on a heated metal surface. The oxygen in the air combines with the metal to form the oxide film, and heat accelerates this combining action.

If solder is to be applied successfully to a metal, the oxides must be removed from the heated metal surface as fast as they form. This can be accomplished by applying, along with the solder, an additional material called *flux*. For good radio work, this flux is always rosin (an amber-colored substance which remains after oil of turpentine is distilled out of crude turpentine). Sheet metal workers generally use an acid flux (usually some form of hydrochloric acid); this is more effective than rosin, but it *has a corrosive action which makes it unsuitable for radio work.*

Flux can be applied either in the form of a liquid or a paste, but it is more convenient to use a special radio solder having a core of the desired flux. In this way, both the solder and the flux are applied at the same time.

How Fluxes Work. Acid and rosin fluxes act in the same manner in making a lead-tin mixture (solder) adhere to another metal. These fluxes dissolve some of the oxides which are always present on a metal surface. The oxides then flow off the metal in liquid form, carrying along dirt, grease, and other oxides so as to leave a clean metal surface to which solder can adhere.

Disadvantages of Acid Flux. Although it is a well-known fact that acid flux or acid-core solder is easy to use, it is unfortunate that some of the acid *always* remains on the work and creeps over to unsoldered portions. In time, this acid will eat away the copper or brass around the joint, causing failure of the joint. The slightest presence of moisture in the air will speed up the creeping movement of acid flux. The acid may travel through the insulation between radio parts, thereby forming leakage paths for electric currents and impairing the efficiency of the circuit.

Because of its strongly corrosive action, acid flux should never be used for radio work.

Rosin Flux. Rosin is a solidified material when at normal room temperatures, but becomes liquid when heated by a soldering iron. Rosin is a fairly good insulator and has no corrosive action on metals. Rosin flux is considerably harder to use successfully than acid flux, but because of its superior insulating and non-corrosive qualities, rosin is by far the best flux for radio connections. It is generally used in the form of rosin-core solder.

Paste Fluxes. Both rosin and acid fluxes are available in the form of pastes which can be applied to the joint with a knife or a wooden splinter. A paste flux is fairly easy to use, but it is difficult to determine whether a particular paste includes corrosive ingredients which can ruin a radio

SPECIAL NOTICE CONCERNING PART 6-8

As Part 6-8, we now supply a 250,000-ohm potentiometer having a long, round control shaft and an a.c. power switch attached to it instead of the unit illustrated in your 6RK Instruction Manual. Ignore the two terminals that project out of the bakelite section at the back of the switch in performing the experiments of Kit 6RK.

To operate this control after mounting it on the chassis, turn the control shaft with your fingers as far as it will go to the left, then turn it to the right until you hear a snapping sound. This sound indicates that the power switch is in the ON position. The control may now be used like any other potentiometer, the normal resistance range being between the extreme clockwise (right) position and the counter-clockwise (left) position where force is needed to open the power switch.

PACKING AND RETURNED MATERIAL SLIP

READ AND KEEP THIS. IT'S IMPORTANT TO YOU.

It is our policy to replace, without charge, missing parts and material which arrives in a damaged or defective condition.

To replace material which you lose, break, or damage, use the "Quotation and Order Blank" enclosed with each Kit.

Check the contents of Kit packages, item by item, against the list printed in the instruction manual.

If any parts seem to be missing, especially small ones, search carefully through the carton, packing, and envelopes, and be on the lookout for substitute parts. If, after a thorough search, a part cannot be found, write us. Do not use this form to report missing Kit parts.

THIS FORM MUST BE INSIDE EVERY PACKAGE OF MATERIAL RETURNED TO US

Sometimes, due to rough handling, a part may arrive in a damaged condition. Sometimes a part will prove to be defective — you discover this when you do your experiments. However, don't conclude that a part is defective just because you don't get the results you expect from an experiment. Unless examination shows a defect present, write first and tell us why you think a part is defective. You may have made a mistake in your experiment.

DEFECTIVE MATERIAL AND ANY THAT MAY BE DAMAGED UPON ARRIVAL MUST BE RETURNED BEFORE A REPLACEMENT CAN BE MADE. Pack carefully; fill out and enclose this form in the package.

If you feel an explanation in addition to this form is required, write a separate letter and attach it to the outside of the parcel post package with tape or paste. Such letter requires a three-cent stamp in addition to the regular parcel post charge. If you send your package by first-class mail, you can enclose a letter without paying extra postage.

FROM THE ABOVE YOU WILL UNDERSTAND THAT TWO THINGS MUST BE WITH EVERY PACKAGE OF MATERIAL YOU RETURN TO US:

(1) YOUR NAME, ADDRESS, AND STUDENT NUMBER.
(2) YOUR REASON FOR RETURNING IT.

P51-10-650

(See Over)

BE SURE TO FILL OUT AND ENCLOSE ONE OF THESE FORMS
IN EVERY PACKAGE OF MATERIAL RETURNED TO US.

(Read OTHER SIDE before using this form.)

National Radio Institute
16th & U Streets, N.W.
Washington 9, D. C.

Gentlemen: I am returning the enclosed material for the reason I have checked below.

1. ☐ Broken on arrival.

2. ☐ It is defective.

3. ☐ I believe it is defective for the reasons stated in my letter herewith.

4. ☐ You asked me to return this. See your letter. S RK CK

5. ☐ This is extra material which you sent me.

Name ______________________ Student No. ____________

Address ______________________________________

City ____________________ Zone ____ State ____________

DO NOT WRITE IN THIS SPACE

connection. Even pastes which are advertised as being non-corrosive will sometimes cause enough corrosion to ruin a delicate radio joint. For this reason *the use of paste flux should be avoided in radio work.*

Making an Alcohol Burner for Heating a Plain Soldering Iron

If you have a plain soldering iron (Part *1-1A)* in place of the electric soldering iron (Part *1-1)*, you will need a convenient source of heat. A small alcohol burner is ideal for this purpose, as it is easy to make and safe to use. Furthermore, this burner provides an alcohol flame which is ideal for removing enamel insulation from wires.

Parts Needed. The only parts needed for the alcohol burner are a plain medium-sized oil can of the type sold for about ten cents in most dime stores and hardware stores, a lamp wick of the type used in kerosene lamps, and about a pint of denatured alcohol, wood alcohol, grain alcohol, Paco Solvent, or an equivalent alcohol product. These parts are pictured in Fig. 7.

FIG. 7. **Parts needed for making an alcohol lamp, which can be used for heating a plain soldering iron, for removing enamel from wires, and for heating an electric soldering iron in locations where power is not available.**

Unscrew the spout of the oil can. With a hacksaw, cut off the spout about ⅜ inch above the base, as indicated by the dotted line in Fig. 7. You can clamp the small end of the spout in a vise while sawing, for this end will be discarded. Use a fine-tooth hacksaw blade and take light strokes to prevent excessive chattering. Smooth the saw cut with your file, and scrape off all metal burrs.

Roll the lamp wick together lengthwise at one end, and push it through the stub of the spout from the bottom. Let the wick project about ½ inch above the top of the spout.

Fill the can about half full of alcohol, then replace the spout and tighten it. Tip the can upside down for a few seconds so the entire wick becomes saturated with alcohol, then set the can upright and apply a lighted match to the wick. The flame should extend 2 to 4 inches above the wick. The color of the flame depends upon the type of alcohol used; pure grain alcohol will give an almost invisible blue flame, commercial alcohols give a predominantly yellow flame, with only a small blue portion.

The height and size of the flame can be adjusted by pushing the wick in or out of the spout. The more wick there is exposed and the more the wick ends are spread out, the larger will be the flame. If the flame decreases gradually in size, or flickers excessively when the burner is used for some time, loosen the cap about half a turn so that air can get in around its threads. Even a slight breeze or draft in a room will make the flame flicker; if the draft cannot be conveniently eliminated by closing windows and doors, set up boxes or boards around the burner to shield it from the air currents.

The flame can be extinguished simply by blowing it out, or by placing a thimble or small tin can momentarily over the flame to cut off its air supply.

Alcohol evaporates rapidly, so if a considerable amount is left in the can after work is finished, you can pour it back into the bottle or can in which the alcohol was sold. Keep your supply of alcohol tightly capped or corked to minimize evaporation. As an alternative to emptying the burner, you can place a small thimble over the wick.

Holder for Plain Soldering Iron. The soldering iron should always be placed so that the copper barrel is in the upper third portion of the flame. Soot will sometimes be deposited by the flame, so do not allow the flame to touch the copper tip of the iron. The iron should be in a horizontal position, or the handle should be lower than the tip during heating. Heat always travels upward; if the handle were higher than the tip, heat would travel up to the handle and make it uncomfortably hot.

A suitable holder in which the plain soldering iron can be placed *while heating* is illustrated in Fig. *8*. (This holder is used only for heating the iron; the ordinary metal holder shown in Fig. *6* is used to support the heated iron when wires or lugs are being tinned.) You can make this yourself very easily, using a large tin can, a scrap piece of wood, and a few nails, or you can design an equivalent holder from other materials which you may have at hand. Keep in mind that the two purposes of the holder are to prevent the alcohol burner from tipping and to hold the copper barrel of the soldering iron in the upper third portion of the flame.

How to Tell When the Iron Is Heated Sufficiently. An alcohol burner like that described here will ordinarily bring your soldering iron to the correct working temperature in from three to five minutes. After heating for three minutes, apply solder momentarily to a flat surface of the tip; if the solder melts readily, the iron is ready for use. If the solder melts slowly, continue heating for a while and then repeat the test. Ordinarily, it is best to heat the iron for about one minute after solder first begins to melt on the tip; extra heat is then stored in the copper barrel and tip, and a number of joints can be soldered before the iron needs reheating.

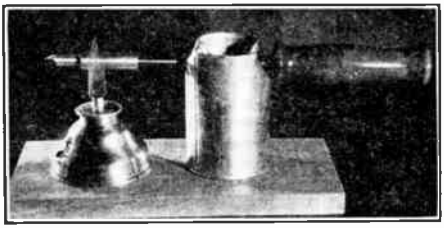


FIG. 8. Completed alcohol burner in use. The base is a wooden board of any convenient size. Three finishing nails hold the oil can in position on the base and prevent accidental tipping. A large empty tin can with notches cut in opposite sides can be used as a holder for the soldering iron, or you can cut a holder out of sheet metal for this purpose. The holder can be fastened to the base with two wood screws, in a position such that the copper barrel will be in the upper third portion of the flame.

Do not overheat the iron; above all, never allow a soldering iron to become red hot. *Too hot* an iron is just as bad as *too cold* an iron insofar as good soldering is concerned, and an excessively hot iron quickly becomes corroded.

Starting the Experiments

Choosing a Place to Work. The experiments in your Practical Demonstration Course can be performed on almost any type of table or workbench which does *not* have a metal top. Students living in city apart-ments will find that an ordinary folding card table serves nicely. If you will be using the plain soldering iron and alcohol burner, choose a location well away from curtains and other highly inflammable materials. If you will be using the electric soldering iron, you can either place the table near a wall electric outlet, or use an extension cord to bring electric power to your table.

Performing the Experiments. Develop the correct experimental habits right from the start by following a logical procedure for each experiment. Whenever you start a new Manual, always study first the introductory discussions at the beginning of the book. After this, perform the experiments *one at a time*, in the correct order, by observing the following procedures:

1. Read through the instructions and discussions for the entire experiment once very slowly, and study any parts which are not immediately clear to you. Do not touch a single tool or radio part until you make this preliminary study.

2. Lay out on your work table the parts and tools needed for the experiment which is to be performed.

3. Carry out the experiment, one step at a time. Record your results whenever spaces are provided in the Manual for this purpose. Additional observations and comments can be written in the margins of the pages, for future reference.

4. Study the discussion at the end of the experiment very carefully, and analyze your results. After finishing an experiment, you should be able to tell in your own words exactly what you proved and how you did it.

5. Fill out the Report Statement for the experiment just completed. This statement is given at the end of each experiment, and repeated on the inside of the back cover of the Manual, and will be numbered the same as the experiment. Check the statement that completes the question correctly, and copy your answer on the last page of the Manual.

6. When you have completed all ten experiments in a Manual and have answered all of the Report Statements, cut off the last page of the Manual on the dotted line according to the instructions on that page, and mail the Report Statement to NRI for grading. *Do not send in the entire Manual.*

IMPORTANT NOTICE: In order to build the NRI Tester with the parts furnished in the first two Radio Kits, it is absolutely necessary that you perform every step in each of the ten soldering experiments in this Manual. There are about twenty-five soldered joints in the NRI Tester, and these must be made exactly in accordance with the professional soldering techniques presented in this Manual. Furthermore, the ability to make good soldered joints is required in all later experiments as well as in practical radio work. In checking student troubles, NRI has found that poor soldering is more frequently the cause of failure to get proper results than all the other causes combined.

DO NOT SKIP ANY STEPS.

EXPERIMENT 1

***Purpose:* To tin the working tip of your soldering iron.**

Step 1. To determine if plain solder alone (without flux) can be used for tinning a soldering iron, hold the heated iron horizontally in one hand, and melt a small amount (about ½ inch) of plain solder (Part *1-4)* by rubbing it lightly over the flat surface of the tip in the manner shown in Fig. *9*. Wipe off the heated solder with quick strokes of a piece of cloth, and note whether any of the solder clings to the tip. Use several thicknesses of cloth so as not to burn your fingers. If you prefer, you can tack this cloth to a small board and use it like a brush for wiping the iron.

Now file this heated flat surface until it is uniformly clean, using for this purpose the flat file specified in Fig. *2*. Usually the Radiotrician will rest the tip of the soldering iron against a non-inflammable solid object such as a brick or a stove while filing. *Never squeeze an electric soldering iron tightly in a vise.* Note how the heated copper surface changes color soon after being filed. Apply plain solder to the freshly filed surface, wipe off with the cloth, and note how much solder adheres to the tip.

In the case of a plain soldering iron, reheat the soldering iron just before filing, and file rapidly so that the iron will still be hot enough to melt solder after you have finished filing one surface.

Step 2. To determine if rosin-core solder can be used for tinning a soldering iron, file a different surface from that used in Step 1, then rub a small amount (about ½ inch) of rosin-core solder (Part *1-3*, marked with printed letters) lightly over this entire surface. Wipe off surplus solder with the piece of cloth to see if any solder remains on the tip.

Step 3. To complete the tinning of your soldering iron, file the remaining flat surfaces of the heated soldering iron tip until bright. Rub rosin-core solder (Part *1-3*) over the surfaces. Wipe off surplus solder with a cloth, then apply additional rosin-core solder to those parts of the surfaces where solder did not adhere. Repeat until these surfaces are completely tinned, then do the same for any other surfaces which are not completely tinned. Your soldering iron should now be completely tinned on all four surfaces as shown in Fig. *10*.

Step 4. To learn the radio expert's technique for shaking surplus solder off the tip of a soldering iron, apply a small extra amount (about ¼ inch) of rosin-core solder to the heated tip. Now hold the iron firmly by its handle and shake it downward over a box, a board, or newspapers. Practice this several times, until you can flip off surplus solder without getting it on your clothes or scattering it all over the room. Apply more rosin-core solder to the heated tip, but this time wipe it off with quick strokes of a cloth.

Discussion: Plain solder without flux will not ordinarily adhere to a copper surface. You proved this in Step 1 by applying the solder to the heated tip of the soldering iron both before and after filing the tip. You would secure the same results with

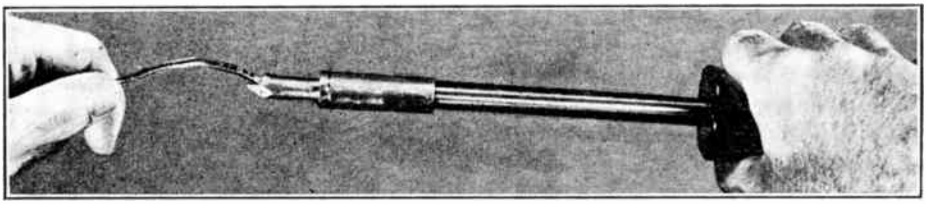


FIG. 9. Correct way to hold the soldering iron while applying solder to one flat surface of the tip for tinning purposes. By keeping the flat surface approximately level, the tendency of the molten solder to roll off the tip is minimized.

copper wire or any other heated copper surface.

The change in the color of the copper surface soon after filing was due to the formation of oxides of copper on the surface. These oxides, along with any other foreign matter which may be on the tip, prevent you from tinning the soldering iron with plain solder. There is no danger of destroying the temper of the file, for an electric soldering iron never gets hot enough to affect the hardness of steel.

In Step 2, you proved that rosin-core solder will adhere to a properly cleaned and properly heated copper surface. Only the surplus solder can be removed with the cloth; the bright silvery surface layer of solder adheres to the clean copper, and cannot be wiped off. In this step, therefore, you tinned one of the four working surfaces of the tip.

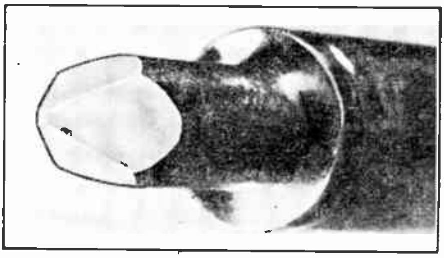


FIG. 10. Close-up photograph showing a properly tinned soldering iron tip. Note that only the flat surfaces of the copper tip are tinned.

Because of its highly corrosive action, *acid-core solder should never be used on the joints in radio and television equipment.* Paste fluxes should also be avoided, even though they are less corrosive than acid fluxes. If you need additional flux, dissolve some powdered rosin in a little alcohol.

Surplus solder often accumulates on a soldering iron during radio work. Rosin flux evaporates quickly from hot solder, so it is usually best to discard this solder. When radio men are in a hurry, they just give the iron an expert flip as described in Step 4, so as to shake off the solder. When the iron is also a bit corroded, however, wiping off the surplus solder with a cloth will usually remove the oxides too, leaving a clean tinned tip.

Tinning serves the dual purpose of *keeping the tip of your soldering iron clean and aiding in the transfer of heat* from the iron to the work. The solder fills small irregularities in the tip and in the work, thus increasing the area of contact between the tip and the work.

A soldering iron which is untinned or only partially tinned on its flat working surfaces quickly becomes pitted and covered with crusts of copper oxide. An iron in this condition is difficult to use, for the oxide has heat-insulating characteristics and thus hinders the transfer of heat.

A certain amount of copper oxide will form even on a properly tinned iron which is used continuously for several hours. This can usually be removed by wiping the tip frequently with a cloth or steel wool as previously explained. The tip should be filed only when a considerable quantity of oxide has formed and cannot be removed by wiping or retinning.

In filing the tip of your soldering iron, always hold the file flat against the surface so as not to change the angle of the tip too much. The tip of your iron has been cut at the angle which has proved most satisfactory for radio work.

Instructions for Report Statement No. 1. The report question which checks your work on this experiment is given below, and repeated on the last page of this Manual. After you have completed the experiment and studied the discussion, read Report Statement No. 1 carefully. Check the correct answer, then copy your results on the report statement page at the end of this Manual. You are asked to specify *the type of solder* (plain or rosin-core) *with which it was the most difficult to tin your soldering iron.* Either the observations which you made during this experiment or the analysis of results in the discussion will give you the answer.

Report Statement No. 1: My untinned soldering iron was *most difficult* to tin with: *plain solder* ☒; *rosin-core solder* ☐.

EXPERIMENT 2

Purpose: **To recognize when solder has hardened, and to see what happens when a joint is moved before the solder has hardened.**

Step 1. To demonstrate how solder changes color as it hardens, hold your heated and tinned soldering iron over a scrap piece of wood with the tip downward, and apply rosin-core solder just above the point of the tip until a solder globule about ⅛ inch in diameter drips down onto the board (the drop is shown in actual size in Fig. *11*). Watch this globule for about a minute, noting the change in color as it hardens.

Drop another globule of solder on the board in this same way, then apply the tip of the iron to the globule and apply additional solder to the tip until this second globule is about twice the size of the first. In the same way, place on the board a third globule which is about three times the size of the first one. As each globule cools, study the changing colors.

Step 2. To find whether larger amounts of molten solder take longer to cool, reheat all three globules of solder on the board one after another as quickly as you can, by applying the heated tip of your soldering iron first to the largest globule, then to the medium-sized one, and finally to the smallest one. Jerk the tip of the iron away from each globule as soon as the solder takes on a silvery molten appearance. While the three globules are cooling together, watch them carefully to see which ones harden first.

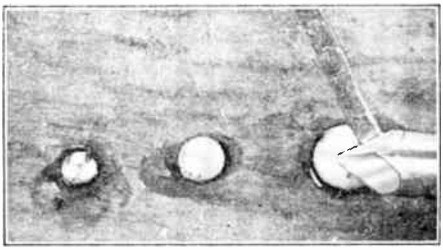


FIG. 11. Method of increasing the size of a molten globule of solder by feeding rosin-core solder to the soldering iron tip while it is in contact with the globule. The three globules used in Experiment 2 are shown clearly in this view. The darker rings on the board around each globule are formed by the surplus rosin flux, which is a yellowish liquid when heated. If you look closely, you will see your own image in the surface of a molten solder globule, just as if it were a tiny curved mirror. The image vanishes gradually as the solder hardens.

Step 3. To determine by actual test the instant when solder hardens, reheat the largest globule with the soldering iron, then remove the iron, and allow the globule to cool. Take the length of stranded enameled aerial wire (Part *1-7H)* and occasionally touch the *top* of the globule gently with it to determine when the solder hardens, while watching the changes in color. Repeat this test a few times if necessary, until you are familiar with the color corresponding to complete hardening of the solder.

Step 4. To see what happens to solder which is disturbed while it is *cooling,* reheat the largest globule with the soldering iron, and hold the wire in the center of the globule while it cools. *Just before the globule turns to a dull silver color,* twist the wire so as to crack the globule.

Discussion: Step 1 showed you that solder has a bright, silvery color (much like mercury) when in a molten condition, and changes gradually in color as it hardens. This change in color serves as a "thermometer" to the Radiotrician, for it tells him when the solder has melted on a joint being unsoldered, and tells him when the solder has hardened sufficiently on a joint being soldered.

Step 2 showed clearly that a large globule of molten solder takes longer to cool than does a small globule. Likewise, you found that the larger globules took longer to heat up.

In the first two steps, we assumed that the solder was hard when it stopped changing color. In Step 3, you probe the solder with the wire, and you prove for yourself that a globule of solder has completely hardened when it changes all over to the characteristic color of hardened solder.

Step 4 demonstrates conclusively a highly important requirement of good soldering: *A soldered joint should not be moved until the solder has completely hardened.* Premature movement cracks the solder, for it is very brittle at the instant of hardening. Solder which is cracked gives very poor electrical contact between the parts of a joint. Provision for holding wires rigid while solder cools is an important part of the procedure.

Instructions for Report Statement No. 2. The test question for this experiment is a simple check of your ability to observe how solder changes in color as it hardens. A correct answer means that you have mastered one important requirement of good soldering, for these color changes tell you when solder has hardened enough to withstand movement.

After you have completed this experiment and studied the discussion, read Report Statement No. 2 carefully, place a check mark in the box which follows the answer you consider correct and copy your answer on the report statement page at the end of the Manual.

Report Statement No. 2: As molten solder becomes hard, it changes from a bright silvery color to: *a bright red color* ☐; *a dull black color* ☐; *a copper color* ☐; *a dull silver color* ☒.

EXPERIMENT 3

Purpose: **To remove insulation from wires and clean the wires preparatory to soldering.**

Preliminary Discussion. Although there is a great variety in the size and general appearance of the conductors used to interconnect (hook up) the various parts (tube sockets, switches. transformers, condensers, etc.) of radio and television receivers and transmitters, there are only two really basic types of conductors. One is the single strand of solid metal wire familiar to everyone. Copper, because of its high conductivity and good mechanical qualities, is the metal from which the wire is drawn. The other type, known as *stranded* wire, consists of several strands of copper wire twisted together to form a single conductor.

The principal difference between the many varieties of solid hook-up wire lies in the diameter of the wire and the kind of insulation surrounding it. The insulation may be any suitable non-conducting material such as silk, cotton, rubber, or enamel. Various plastics also have suitable insulating qualities. The chief purpose of the insulation is to prevent the conducting wire from touching anything that might cause undesirable grounds or short circuits.

Solid wire having no insulation at all is also available. Running the wire through molten solder during manufacture gives it a bright, shiny appearance. Such wire is generally known as tinned bus wire. The coating of solder protects the wire from oxidization and aids in soldering. Tinned, insulated wire is the most widely used hook-up wire for interconnecting the various parts of radio and television equipment.

Stranded wire is almost always insulated, the insulation forming a convenient means of holding the strands together. The individual strands may or may not be tinned, depending on the particular type of wire. Stranded aerial wire, a sample of which is included in this first Radio Kit, does not have insulation over the entire group of wire strands. Instead, each individual strand has a coating of a protective enamel.

Insulated wire, both solid and stranded, is available in a wide variety of colors. The color is used solely for the purpose of tracing and identifying various wires and circuits. This is especially helpful when a number of wires are bound together to form a cable. The color of the insulation has nothing whatsoever to do with the characteristics of the insulation, or the current rating of the wire itself.

In radio work, so-called "push-back" wire is widely used. This is tinned, stranded, or solid wire enclosed in a simple cotton wrap, over which is the regular insulation. The insulation can be slid back when a solder connection is to be made, and then slid toward the connection to form a complete protection.

The wire supplied in your first Radio Kit is typical of the wire you will encounter in radio service work. Stranded and solid wire, tinned and untinned, are included in the Kit to give you experience with the types in general use.

Step 1. To identify the various wires supplied in this Kit, first set aside the three wires which are identical in appearance and construction. These are given the identifying part numbers *1-7A, 1-7B,* and *1-7C,* in the parts list on page 2. They are 8-inch lengths of No. 20, solid tinned push-back hook-up wire.

The length of aerial wire, Part *1-7H,* is readily identified, since it is the only one that does not have cloth-like insulation. Each of the seven strands of this wire is covered with enamel insulation.

Now identify the lamp cord, Part *1-7G.* This is the length of wire having the thickest insulation. The wire itself is made up of untinned strands; the insulation consists of a cotton braid over rubber.

Part *1-7F* is the stranded tinned wire with the glazed insulation; and Part *1-7D* is the stranded tinned wire with plain cloth insulation. Part *1-7E* is the solid untinned insulated wire. It may be necessary to cut away about ⅛-inch of the insulation on these wires to identify them positively.

When you have identified the wires according to the part numbers and descriptions given above, and in the parts list on page 2, place a small piece of ordinary adhesive tape around each wire, and mark its part number on the tape for easy future identification.

Step 2. To remove insulation from push-back insulated hook-up wire, grasp in one hand a length of the *solid* tinned push-back insulated wire (Part *1-7A*), and push the insulation back from the end with the thumb and first finger of your other hand, as shown in the upper view in Fig. *12*. Push the insulation back far enough to expose about ¾ inch of wire. To show that the insulation can be pushed forward again after a joint is made if too much wire was originally exposed, push the insulation forward until only about ¼ inch of wire is exposed. Push back again until the full ¾ inch is exposed. Now push back the insulation on the other end of this wire the same amount (¾ inch); use long-nose pliers this time to hold the end of the wire, as illustrated in the lower view in Fig. *12*.

Also, push back the insulation for ¾ inch from both ends of the *stranded,* tinned, push-back insulated wire (Part *1-7D*). Use long-nose pliers to hold the wire, as illustrated in Fig. *12*.

Step 3. To remove insulation from ordinary insulated hook-up wire by squeezing with long-nose pliers, grasp in one hand the length of solid, untinned, insulated wire (Part *1-7E*), and use your long-nose pliers to squeeze the insulation for a distance of ¾ inch from one end. Figure *13* illustrates how this is done. You will have to apply enough pressure with the long-nose pliers to split the insulation lengthwise, so that you can pull off the strips of insulation with the pliers. The closer you get to the hinge of the pliers, the easier this will be. Loose threads of insulation can then be clipped off with side-cutting pliers or a pocket knife. Remove ¾ inch of insulation from the other end of the wire in the same way. Scrape the exposed copper wire lightly with the blade of a pocket knife as shown in Fig. *15*, to remove oxides and dirt.

In this same manner, remove ¾ inch of insulation from each end of the length of stranded, tinned, No. 20 wire, insulated with rubber and cotton braid (Part *1-7F*).

If you are unable to break the insulation by squeezing, omit this step and apply to this same wire one of the alternative methods given in the next step.

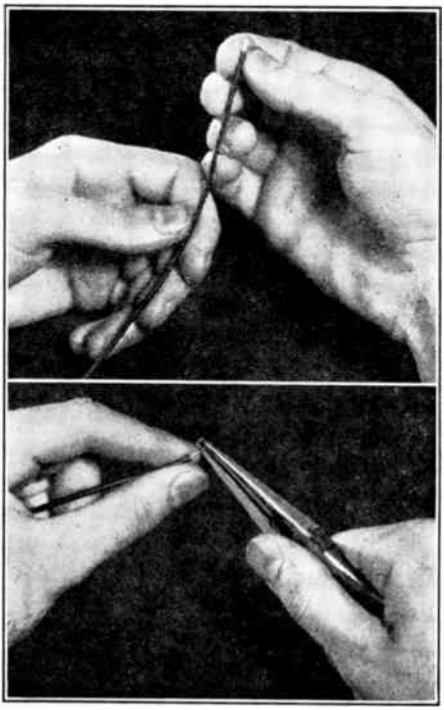


FIG. 12. The correct method of pushing back the insulation of solid push-back insulated wire with the fingers preparatory to soldering is shown in the upper view. The same method is used for stranded wire of this type. When the insulation cannot readily be pushed back far enough with the fingers, it will be easier to grasp the bare end of the wire with your long-nose pliers, as illustrated in the lower view. When holding the wire with pliers in this manner, it is a simple matter to push the insulation back with the fingers as much as desired.

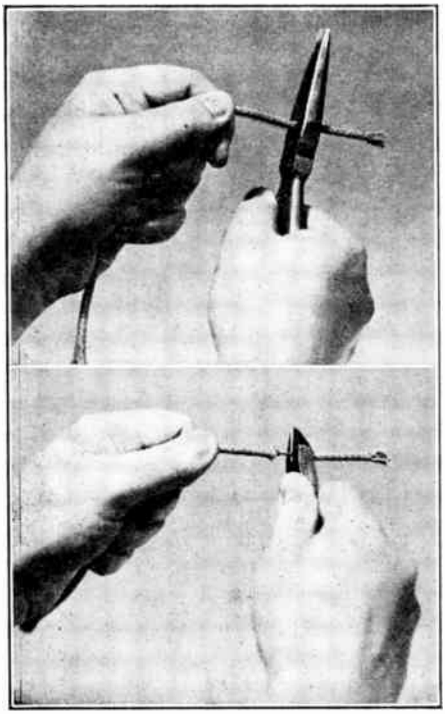


FIG. 13. This shows how to use a pair of long-nose pliers to squeeze the insulation on a piece of ordinary insulated wire so it can be removed more easily. If your pliers have wire-cutting jaws near the pivot, you will have to place the wire closer to the end of the pliers. Sometimes it is convenient to use a pair of sidecutters to remove insulation. This is done by *carefully cutting only the insulation*, and then pulling the insulation free by moving the sidecutters toward the end of the wire.

Step 4. To remove insulation from ordinary insulated wire with a pocket knife, hold the length of No. 18 stranded lamp cord (Part *1-7G)*, flat upon your workbench or on a block of wood. Cut through the insulation all around the wire at a point ¾ inch from one end by moving the blade of a sharp pocket knife across the insulation with a sawing motion while rotating the wire slowly with your fingers. This is illustrated in Fig. *16*. Continue until the outer covering of woven cotton thread has been cut through all around, then slide this covering off over the end of the wire with your fingers or by pulling with long-nose pliers. Be careful not to cut through the inner rubber layer to the copper strands. Once the inner rubber insulation is partly cut through, peel it off with your fingers or a knife.

Scrape the exposed wire lightly with your knife blade if the copper appears corroded or dirty; do this several times, spreading out the strands each time so as to expose a different part of each strand to the knife.

Now take the other end of the lamp cord wire, hold it in your hands as shown in Fig. *17*, and slice off the outer braided cotton covering for a distance of ¾ inch from the end. Peel away the remaining rubber insulation with your knife and fingers,

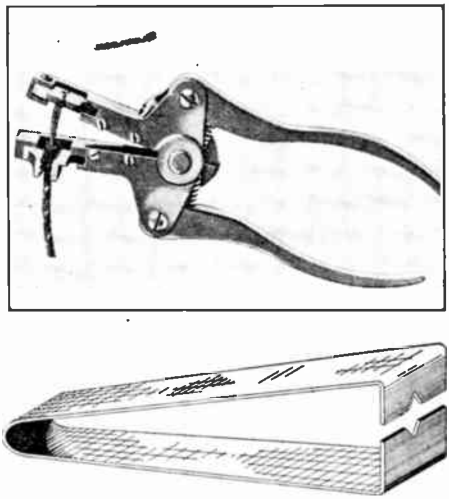


FIG. 14. These instruments are often used to remove insulation from various types of wire used in radio work. The wire strippers shown at A are generally used in production work. The bent strip of metal shown at B is a very convenient wire stripper for general radio service work.

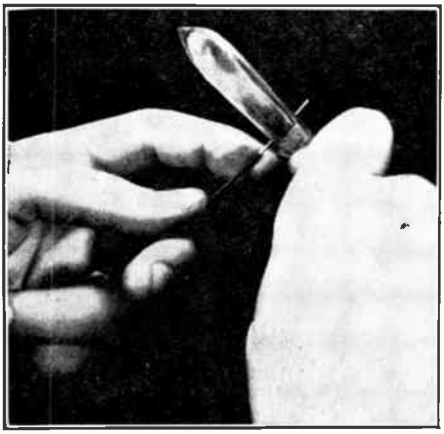


FIG 15. Always use the portion of your pocket knife blade closest to the handle for scraping oxides and dirt from exposed copper wire preparatory to soldering. This preserves the main part of the blade for purposes where sharpness is required, such as when cutting through braided cotton insulation.

and trim off loose threads. Be careful not to cut or nick any of the copper strands. Scrape the strands with the knife blade until all are clean and shiny.

Step 5. To remove enamel insulation from a wire, take the length of enameled aerial wire (Part *1-7H)* and untwist the wires for about 1½ inches at one end. Using your knife blade, scrape off the enamel from each of the seven strands of wire, one at a time, for a distance of ¾ inch from the end. Do this carefully and thoroughly, to give clean copper surfaces without nicking any of the wires. Leave the wires like this for a future experiment.

If you have an alcohol burner, use it to burn off the enamel at the other end of the aerial wire. Untwist the strands for about 1½ inches, and spread them out just enough so that none touch each other. Light the alcohol burner, and hold the spread-out strands just within the tip of the inner cone of flame, as shown in Fig. *18,* until the wires are red hot for about ¾ inch from the end. Now immerse the heated wires quickly in a little pan of alcohol. Repeat if any enamel remains on the ends of the wires and can't be rubbed off with a cloth. If you do not have an alcohol burner, use the scraping technique for both ends of this wire.

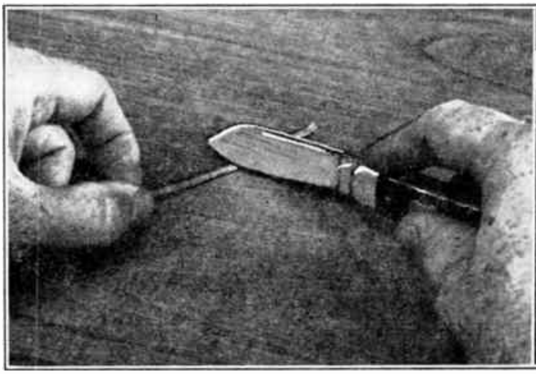


FIG. 16. When the insulation on a wire is too tough to be broken by squeezing with pliers, the pocket knife technique illustrated here is employed by some radio men for cutting through the outer braided covering on the wire. *The knife must be sharp,* and must be held lightly so as to avoid cutting too far and nicking or breaking the copper wire.

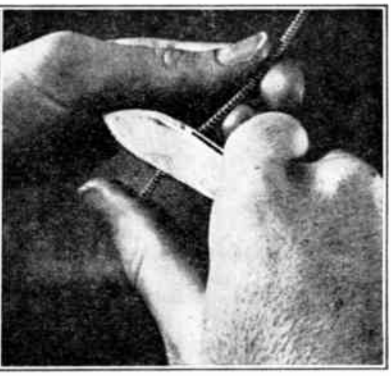


FIG. 17. This method is employed by radio men for cutting away the insulation from a wire which is anchored at its other end. The knife must be sharp, and extreme care must be used to avoid nicking solid copper wire or cutting strands in the case of stranded wire.

Discussion: Tinned push-back insulated hook-up wire, either solid or stranded, is the type of wire most commonly used by radio men. The copper wire is tinned during manufacture so that insulation slides along it readily, and the insulating cotton covering has a special weave which permits compressing the insulation. Solid push-back hook-up wire is supplied in your next radio Kit for use in hooking up practical radio circuits for demonstration purposes, so you will get plenty of experience with this type of wire.

Ordinary insulated wire (not of the push-back type) is used for the power line cords of radio receivers, and is occasionally used for receiver wiring as well. A highly convenient way to remove insulation from wire of this type is by squeezing with pliers as explained in Step 3, but there will be times when you will have to cut away the insulation with a pocket knife as explained in Step 4. Whenever you use a knife for removing insulation or scraping wire, however, *try to avoid cutting or nicking the wire.* Even the slightest nick will weaken the wire enough to cause a break eventually at that point, if the wire is subject to considerable bending or vibration.

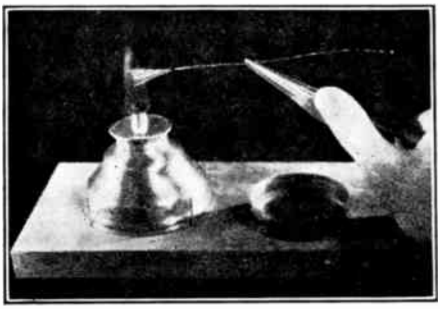


FIG 18. If enamel-covered wire is held just inside the tip of the *inner cone* of an alcohol burner flame as illustrated here, the wire will become red hot and the enamel will burn off. The inner cone appears darker in color than the outer cone. If the room is drafty due to air currents, the flame will flicker and make heating difficult; a few boxes or boards set up around the flame will prevent this flickering. Some experimentation may be necessary to find the portion of the inner cone which will heat the wires red hot, for other portions of the flame will not remove the enamel and oxides.

Scraping with a knife blade as described in Step 5 is the method used most often by radio men for removing enamel insulation from a wire. Use only a small portion of the knife blade near the handle for scraping wires, as this dulls the blade quickly. The main part of the blade should be kept as sharp as possible, for cutting purposes.

A small piece of fine sandpaper can be used for removing enamel insulation with no danger of nicking the wire. Simply fold the sandpaper over the wire, then pull the wire out from the sandpaper. Repeat as many times as necessary to remove all enamel. A few trials will tell you how hard to press the sandpaper between your fingers while drawing out the wire. Stranded enameled wire can be cleaned in this same way if the wires are spread out and are turned a little each time so as to expose all of their surfaces to the sandpaper; this is illustrated in Fig. *19.*

Burning off enamel with an alcohol burner gives a better job than scrapping, and eliminates the possibility of damaging the copper wire. The tip of the inner cone in the flame is hot enough to make the wire red hot and remove the enamel and oxides. Plunging the hot wire quickly into alcohol prevents the cleaned wire from tarnishing while cooling. The same alcohol used for the burner can serve for this purpose; the alcohol can be poured back in the bottle after you have finished with it.

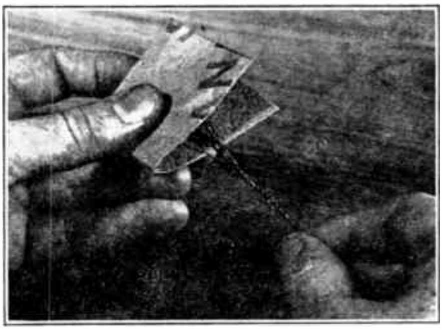


FIG. 19. Method of using fine sandpaper (about Number 00) to remove enamel insulation from stranded wire. Press the folded sandpaper (a piece about one inch wide and two inches long) together with the wire in between as indicated, then draw the wire out. Repeat this procedure until all the enamel has been removed from each strand of the portion of the wire which is to be tinned or soldered.

The samples of wire supplied you for the experiments in this Manual are long enough so that you can cut off an inch or so of wire from an end and repeat the experiment in case you accidentally damage the wire. Do not cut the wires any shorter than 5 inches, however, for you will need these wires later for practicing actual radio connections.

Instructions for Report Statement No. 3. After completing this experiment and studying the discussion, read Report Statement No. 3 carefully. Place a check mark in the box following *the type of wire which you found easiest to prepare for soldering.* Then copy your answer on the last page of this Manual.

Report Statement No. 3: The wire which I found *easiest* to prepare for soldering by pushing back or removing insulation was: solid tinned *push-back wire* ☒; *solid untinned insulated wire* ☐; *stranded untinned lamp cord* ☐.

EXPERIMENT 4

Purpose: **To tin hook-up wire.**

Step 1. To learn how to tin solid wire properly, practice by using the *solid* untinned wire (Part *1-7E)* from which you have already removed the insulation at the ends and cleaned the exposed copper. Leave the heated soldering iron in its holder with the tip facing you. Hold the wire in one hand with one end resting on a flat surface of the soldering iron tip, then apply solder to the *wire* with the other hand, as illustrated in Fig. *20.* Slide and rotate the wire slowly between the iron and the solder until the wire is completely tinned. Shake off surplus solder from the wire. Tin the other end of this wire in the same way.

Step 2. To learn how to tin stranded wire properly, untwist the exposed and cleaned strands at one end of the lamp cord wire (Part *1-7G)* so that the strands are separated from each other for a distance of about ½ inch from

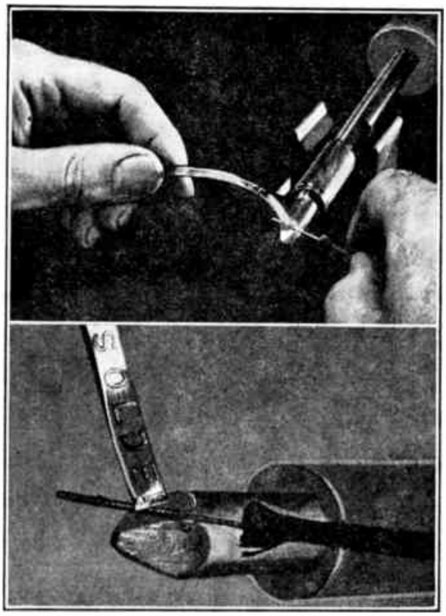


FIG. 20. Method of holding the solder and wire when tinning either solid or stranded wire. The heated soldering iron is left in its holder. The close-up photo shows a partly tinned wire. Slide the wire back and forth between the soldering iron tip and the solder until it is completely tinned for about half an inch from the end.

the end, as shown in Fig. *21*. Tin this wire by applying solder to one side of the strands while heating them from the other side with the soldering iron, just as you did in Step 1. When all strands have been tinned for ½ inch from the ends, shake off surplus solder from the strands while the solder is still in molten form, or simply tap the strands with the heated soldering iron. After the wire has cooled, twist the strands together again. If you have difficulty in getting the strands twisted tightly (see Fig. *21G)*, heat them a little with the soldering iron. Stranded wire at various stages of this tinning process is illustrated in Fig. *21*. Tin one end of the 7-strand enameled aerial wire (Part *1-7H)* in this same manner.

Now tin the untinned end of the lamp cord wire (Part *1-7G)* with the strands twisted together, by following the tinning procedure given in Step 1. Tin the untinned end of the enameled aerial wire (Part *1-7H)* in this same way (with the strands twisted together).

Discussion: Solid wire is remarkably easy to tin if clean. New wire can usually be tinned without cleaning, but old wire should be scraped clean first. It is usually sufficient to tin the wire up to about ¼ inch from the insulation; if you go much closer than this with the soldering iron, there is danger of burning the insulation.

Untinned stranded wire is often difficult to tin properly unless the strands are individually cleaned and the procedure given in Step 2 is followed completely. If properly done, the tinned wire can be twisted together again. Difficulty in tinning stranded wire means that additional careful scraping is necessary.

With new and fairly clean stranded wire, it is possible to tin the wire without untwisting, just as if it were a solid wire. There are two drawbacks to this short-cut method. First and most important, *the inside strands may not be thoroughly tinned.* Second, after tinning, the wire will be so stiff that bending it to form a joint may be quite difficult.

Instructions for Report Statement No. 4 After completing this experiment and studying the discussion, read Report Statement No. 4 carefully, then place a check mark in the box following the answer which you believe tells when you will get *more thorough tinning of stranded wire.* Then copy your answer on the last page of this Manual.

Report Statement No. 4: Stranded wire can be tinned *more thoroughly: while the strands are twisted together* ☐; *while the strands are untwisted and spread out for individual tinning* ☒.

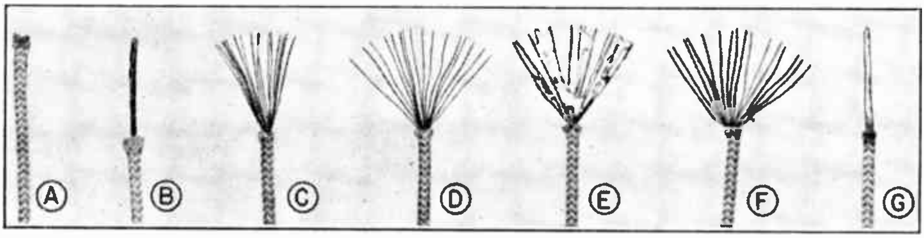


FIG. 21. Steps in preparing one end of the lamp cord (Part *1-7G*) which has rubber insulation covered with cotton braid. *A*—Original wire; *B*—Wire with insulation removed from end; *C*—Strands spread out for cleaning; *D*—Cleaned strands ready to be tinned; *E*—Completely tinned strands; *F*—Tinned strands after surplus solder has been removed; *G*—Tinned strands twisted together again.

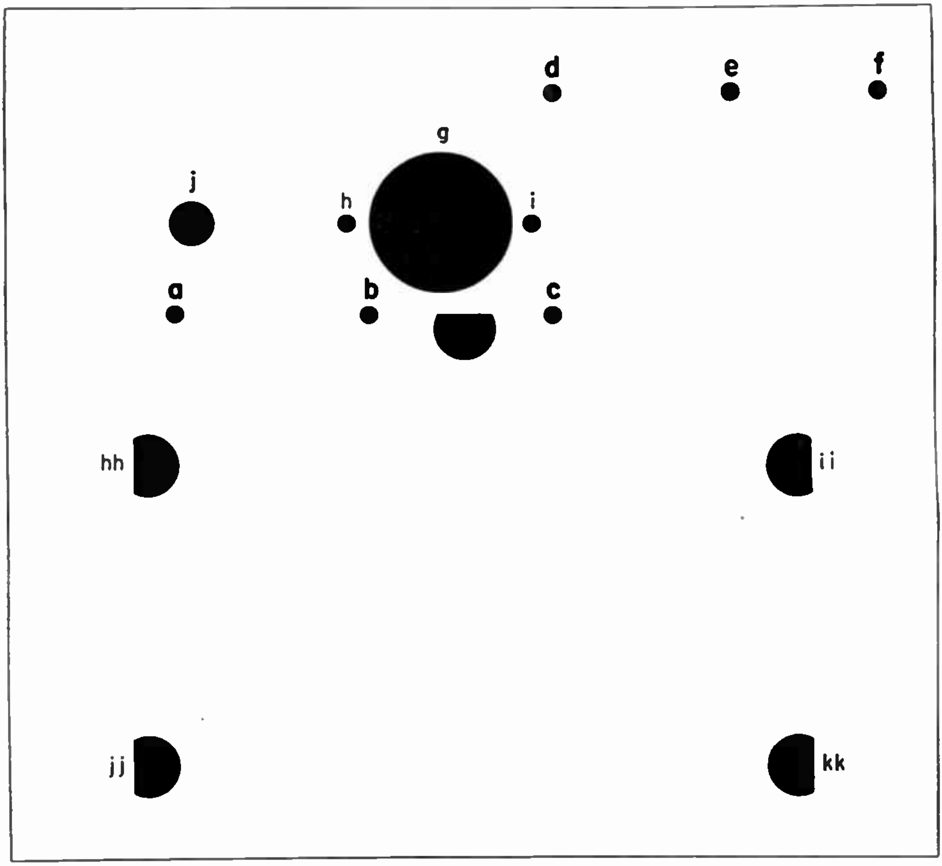


FIG. 22. **Bottom view of the metal chassis, Part *1-11*. The front edge of the chassis has three holes and is bent in the same direction as the sides. The back edge of the chassis has no holes, and is bent in the opposite direction from the other three edges. The large letters *a, b, c, d, e,* and *f* can be placed alongside the holes with a metal-marking crayon, ordinary soft lead pencil, or with pen and ink.**

EXPERIMENT 5

***Purpose:* To mount soldering lugs on a metal chassis and prepare them for soldering.**

Step 1. Mount the three tinned soldering lugs (Parts *1-8A, 1-8B,* and *1-8C) in holes d, e, and f respectively on the bottom of the metal chassis* (Part *1-11*), in the following manner: Place the chassis on your table, bottom up, locate the six holes which are to be used for lugs in this experiment, and mark them with a metal-marking crayon as indicated in Fig. *22*.

Now bend a tinned lug *(1-8A)* at an angle of about 45°, using long-nose pliers as shown in Fig. *23*. Insert a machine screw (Part *1-9A)* in hole *d* from the top of the chassis, and hold the head of the screw in place with a finger. Place lug *1-8A* over the screw from the bottom of the chassis, with the bent part of the lug away from the chassis, then place a nut (Part *1-9B)* on the screw and tighten it with your fingers.

Hold the nut and lug with ordinary all-purpose pliers in the manner shown in Fig. *24A*, so that the lug points

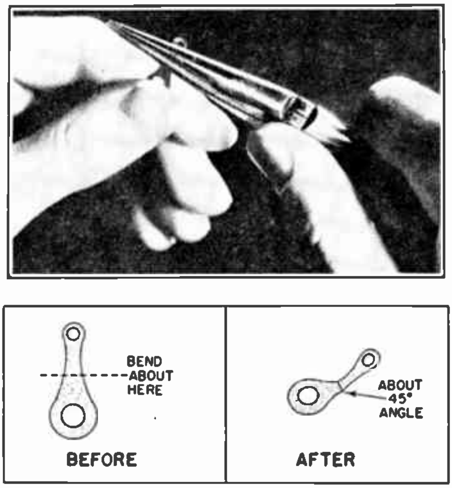


FIG. 23. Method of bending a soldering lug with long-nose pliers. Bending should be done *before* the lug is bolted to the chassis; once a flat lug is bolted to a chassis, it is difficult to pry the lug upward to a convenient soldering position.

toward the back of the chassis, and tighten the bolt head from the top of the chassis with a medium-sized screwdriver as shown in Fig. *24B.* Now bend the other two tinned lugs *(1-8B* and *1-8C),* and fasten them in holes *e* and *f* respectively, with screws and nuts in exactly the same way. These three tinned lugs are now ready for use.

Step 2. To get experience in tinning untinned lugs before they are mounted, take untinned lug *1-8D* and file both sides of the lug at the end having the smaller hole, until the copper shows clean and bright at this end of the lug. Scraping the lug with your pocket knife blade is an alternative cleaning method. Now hold the cleaned part of the lug against a flat face of the heated soldering iron tip with long-nose pliers, and rub *a small amount* (less than ¼ inch) of rosin-core solder over the uppermost cleaned surface as shown in Fig. *25.* Turn the lug over and apply solder to the other side. Rub the lug back and forth over the iron to spread the solder and make it adhere to the cleaned surfaces.

To remove surplus solder after tinning, hold the lug with the pliers in one hand, heat the lug with the soldering iron held in the other hand, then tap the lug gently against the tip of

FIG. 24A. One method of using ordinary all-purpose pliers to prevent the soldering nut and lug from turning as screw is tightened.

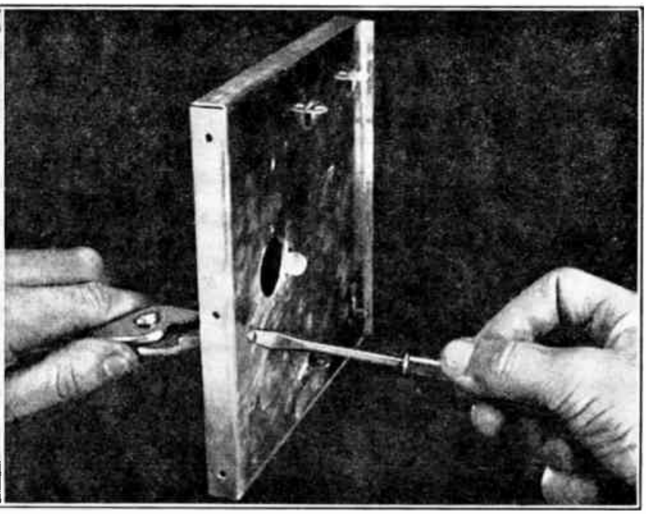


FIG. 24B. Another method of holding a nut with ordinary pliers while tightening a machine screw which is being used for mounting a soldering lug underneath the chassis. The screw should be tightened enough so that the lug cannot readily be moved with the fingers.

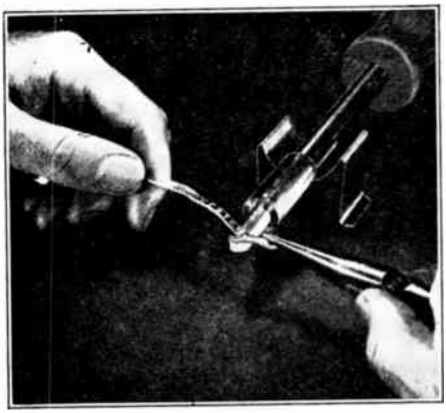


FIG. 25. Method of tinning a lug prior to mounting it on a chassis. This technique is used only for untinned lugs, or for tinned lugs which have become coated with oxides and dirt.

the iron to shake off surplus molten solder. (Sometimes it is more convenient to wipe off the surplus molten solder from the lug with a cloth.) Bend the lug approximately at its center, using pliers and fingers as shown in Fig. *23*, then mount this lug in hole *a* on the bottom of the chassis as shown in Fig. *26*.

Using the same methods, clean lug *1-8E* by filing or scraping, then proceed to tin the lug and remove surplus solder. Bend the lug at a 45° angle just as you did for the other lugs, then mount this lug in hole *b* on the chassis.

Step 3. To get experience in tinning an untinned lug which is already mounted on a chassis, bend lug *1-8F* in its center about half as much as you bent the other lugs, then mount this lug in hole *c* on the bottom of the chassis. Scrape the exposed upper half of the lug with the knife blade until clean, then hold the heated soldering iron against the top of the lug for a few seconds. Now slide the soldering iron down along the lug far enough so you can apply rosin-core solder directly to the top of the lug, and rub the solder over the lug by sliding the iron back and forth. Apply additional solder if some parts of the lug near the small hole are untinned, but use as little solder as possible in order to avoid having surplus solder roll down the lug to the nut.

Step 4. To practice removing surplus solder from a mounted soldering lug, use a cloth to wipe as much surplus solder as possible from the tip of

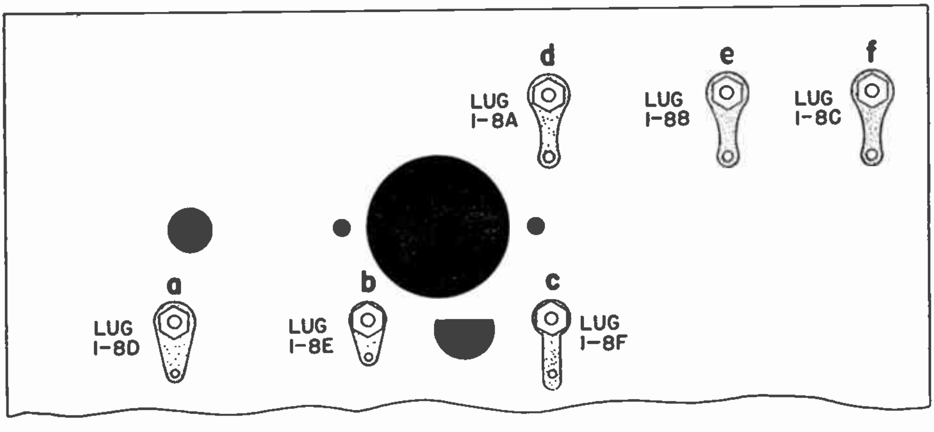


FIG. 26. Upon completion of Experiment 5, you should have six soldering lugs, all tinned, mounted on the chassis exactly as shown here, and with the ends of the lugs bent upward as shown in Fig. 23. Note that the letters in the part numbers identifying the various lugs do *not* correspond to the letters identifying the chassis holes in which the lugs have been mounted.

the heated soldering iron, then apply the iron to lug *1-8F* so as to pick up some of the surplus solder on the lug. Wipe this solder from the iron, then repeat the process as many times as are necessary to get the solder out of the small hole in the lug. Sometimes solder can be poked out of the hole by inserting the cleaned tip of the soldering iron in the hole. The six lugs should now appear as shown in Fig. *26*.

Discussion: Separate soldering lugs like those supplied in this Radio Kit are used chiefly for making connections to a metal chassis. Wire could be soldered directly to the chassis in some cases, but chassis metals are usually difficult to tin, and require more heat than can be supplied by the average radio soldering iron. Furthermore, a soldered connection to a flat metal surface is usually messy in appearance. Remember that tinned soldering lugs similar to those you mounted in Step 1, or lugs which you have previously tinned, should be used for making soldered connections to a chassis or any other large metal surface.

It is generally easier to bend soldering lugs before they are mounted. Bending a lug away from the chassis makes it easier for you to attach wires to the lug. As a general rule, bend a lug approximately in its center. Hold the small end of the lug with the pliers, for you can bend the large end more readily with your fingers.

When using a soldering lug, you ordinarily apply solder only to the bent-up half of the lug, hence only this portion need be cleaned and tinned. When the lug is unmounted, it is best to clean and tin both sides in the vicinity of the smaller hole. When a lug is mounted on a chassis, only the uppermost surface is cleaned and tinned, for it is difficult to work on the underneath surface.

Some soldering lugs which appear to be tinned are actually coated with nickel, a metal to which rosin-core solder does not readily adhere. With lugs like this, scrape or file away the nickel surface so as to expose the brass or copper underneath.

The secret of tinning a soldering lug properly lies in applying the rosin-core solder directly to the lug, a small distance away from the soldering iron tip. The rosin flux can then act on the lug. If the solder rolls off, the lug is too hot and should be allowed to cool for a few seconds. Insufficient cleaning and tinning is indicated when you can wipe off solder completely from parts of the lug. Rubbing the soldering iron tip back and forth over the top of the lug helps to make the solder adhere.

When a soldering lug is being tinned, the hole in its small end usually fills with solder. This hole must be opened to permit looping the connecting wire through the hole. Brushing out the solder is bad practice, for it scatters molten solder in all directions and may result in short circuits. One technique for getting out this solder is given in Step 4; practice this several times by filling the holes again with solder after you have cleaned them out, and you will soon find yourself lifting off surplus solder just as speedily as does an experienced serviceman. Incidentally, some servicemen do not bother to remove surplus solder from the hole; when ready to make a connection, they simply apply the soldering iron to melt the solder, then poke the wire through the hole. Shake surplus solder from the iron whenever necessary, and wipe the soldering iron frequently with a cloth. The less solder on the iron, the more solder you can pick up.

Instructions for Report Statement No. 5. After completing this experiment and studying the discussion, read Report Statement No. 5 carefully, place a check mark in the box following *the correct method of connecting a hook-up wire to the metal chassis of a radio receiver.* Then copy your answer onto the last page.

Report Statement No. 5: When a wire is to be connected to the chassis of a radio receiver, the wire should be: *soldered directly to the chassis* ☐; *soldered to a tinned lug which has been bolted to the chassis* ☒; *pushed into any convenient hole in the chassis and soldered* ☐.

EXPERIMENT 6

Purpose: **To secure practical experience in making temporary and permanent soldered connections to lugs.**

Step 1. To make a temporary hook joint to a soldering lug with solid wire, bend one end of a length of the solid, tinned push-back wire (we will designate this as Part *1-7A)* into a hook by using long-nose pliers, as illustrated in Fig. *27.* Insert this hook in the hole in *lug 1-8D,* starting from the bottom of the lug as shown in Fig. *28A.* Bend the hook a little more after inserting, if there is any tendency for the wire to fall out, but do not pinch the hook together for this temporary joint.

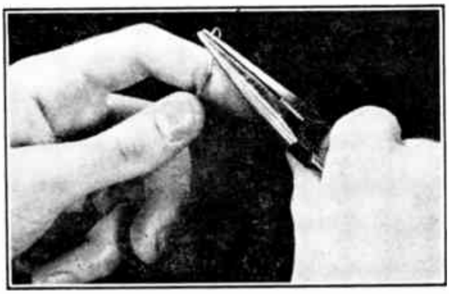


FIG. 27. Forming a hook on solid wire with long-nose pliers, preparatory to making a soldered hook joint.

Now apply the hot soldering iron to one side of the wire in the lug, and apply rosin-core solder directly to the wire and to the lug, as in Fig. *28B.* Apply just enough solder to fill the gap between the lug and the upper part of the hooked wire, then remove the soldering iron. Do not move the wire until the solder has hardened. The finished temporary hook joint is shown in Fig. *28C.*

IMPORTANT. The soldering tip must make good contact with both the lug and the wire, so as to heat and solder both parts of the joint.

Step 2. To make a temporary hook joint to a soldering lug with stranded wire, take the stranded push-back wire (Part *1-7D),* twist the strands

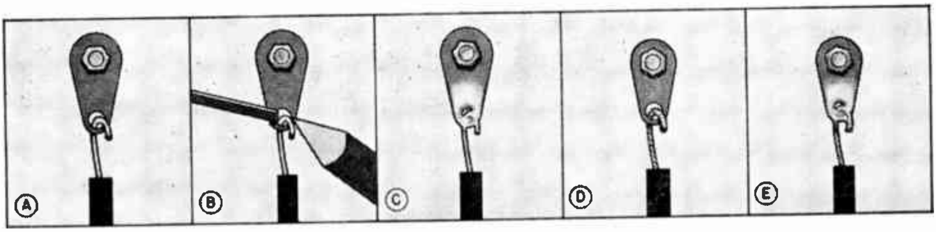


FIG. 28. Temporary connections to soldering lugs. *A*—Temporary hook joint to a soldering lug with solid wire, before soldering; *B*—Method of soldering a hook joint on a soldering lug. Note that the soldering iron is held on top of the lug, on one side of the wire, and solder is applied to the other side of the wire; *C*—Your temporary hook joint with solid wire should appear like this after soldering; *D*—Temporary hook joint with stranded wire, before soldering; *E*—Temporary hook joint with stranded wire, after soldering.

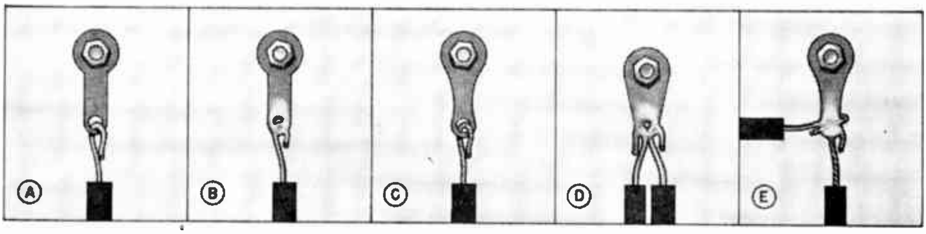


FIG. 29. These illustrations show essential features of various soldering lug connections. Note how the solder joins the wire and the lug into a single unit. This is possible only when the *work* is heated sufficiently to melt the solder into a liquid. *A*—Permanent hook joint with solid wire, before soldering; *B*—Permanent hook joint with solid wire, after soldering; *C*—Permanent hook joint with stranded wire, before soldering; *D*—Two temporary hook joints to a lug with solid wire, after soldering; *E*—Two permanent hook joints to a lug, after soldering.

together with your fingers if they have become unraveled, bend the end into a hook, insert the hook in *lug 1-8E* from underneath as shown in Fig. *28D*, and solder the joint exactly as instructed in Step 1. The soldered joint should appear as in Fig. *28E*,

Step 3. To make a permanent hook joint to a soldering lug with solid wire, take another length of solid push-back wire (we will designate this as Part *1-7C),* bend a hook in one end with long-nose pliers, and insert the hook in *lug 1-8F* from underneath just as you did in Step 1. Squeeze the hook together with long-nose pliers so that it resembles Fig. *29A*, then solder the joint according to the instructions in Step 1. The final soldered joint is shown in Fig. *29B*.

Step 4. To make a permanent hook joint to a soldering lug with stranded wire, take the stranded hook-up wire (Part *1-7F),* twist the strands together with the fingers if necessary, bend the end into a hook, insert the hook in *lug 1-8A* from underneath, squeeze the hook together tightly with long-nose pliers as illustrated in Fig. *29C*, and solder the joint as instructed in Step 1.

Now take the stranded lamp cord wire (Part *1-7G*) and make the same type of permanent hook joint to *lug 1-8B*, using that end of the wire which was tinned *without untwisting the strands.*

Finally, take the stranded enameled aerial wire (Part *1-7H)* and make a permanent hook joint with either end of it to *lug 1-8C*, then solder it.

Step 5. To make a temporary hook joint to a soldering lug which already has one connecting wire, take the remaining length of solid push-back wire (this will be designated as Part *1-7B)* and form a hook at one end with long-nose pliers. Apply the heated soldering iron to the solder at the top of *lug 1-8D* so as to melt the solder, then insert the hook of your wire in this hole from underneath while holding the soldering iron on the top or side of the lug so as to keep the solder in a molten state. When both wires are hooked through the hole in the lug as shown in Fig. *29D*, remove the soldering iron and allow the joint to cool.

Step 6. To make a permanent hook joint around a soldering lug instead of through the hole in the lug, take the length of solid untinned wire (Part *1-7E)*, form a hook at one end with long-nose pliers, loop this hook around *lug 1-8A* just behind the existing connection to this lug, as shown in Fig. *29E*, squeeze the hook tightly over the lug with long-nose pliers, then apply rosin-core solder to one side of the hook and to the lug while holding the heated soldering iron on the other side of the hook.

Step 7. To secure practice in "dressing" wires neatly, first compare your work carefully with the illustration in Fig. *30* to make sure that your wires are on the correct lugs (again note that letters identifying the chassis holes and the solder lugs do not correspond), then straighten out each wire with your fingers and arrange them all neatly in the manner shown in Fig. *30* so they will be ready for the next experiment.

Now apply the heated soldering iron to lug *1-8A* so as to melt the solder on stranded wire *1-7F*, then grasp this wire with long-nose pliers and hold it rigidly in position at the angle shown in Fig. *30*, while the solder is hardening. Rest either your hand or the pliers on the chassis.

Discussion: Soldered connections to soldering lugs are among the most common which you will make in your radio work. In this experiment, you make such a wide variety of connections to soldering lugs that you are prepared for just about any type of soldering lug connection you may require in professional radio work.

A temporary connection is made only when you are reasonably sure that you will have to remove the wire in the near future. A permanent joint differs from a temporary joint only in the squeezing of the hook prior to soldering. A permanent connection is always more satisfactory, and should be used whenever there is any chance at all that the joint may be in use for some time. The permanent connection possesses mechanical strength as well as good electrical contact; thus, a good permanent connection will withstand pulling and will serve its electrical purpose even before it is soldered.

To avoid burning the insulation on a wire when soldering, it is best to bend the hook in such a way that all insulation will be at least 1/8 inch away from the lug when the wire is in soldering position. In the case of push-back wire, this insulation can be pushed right up to the lug after the joint is soldered; with other types of wire, the insulation cannot be moved.

Remember, *a joint must not be disturbed while the solder is hardening.* If the wire will not remain in position by itself during this time, hold it rigid with your hand. If you rest your hand on the chassis when doing this, you will have no difficulty in holding a wire without appreciable movement for the few seconds required for the solder to harden. Joints must often be remelted to change the positions of wires, so the experience you secure in Step 7 is particularly valuable.

Solder which is on a lug or wire hardens far more rapidly than a globule of solder on a board, because lugs and wires conduct heat away from the solder and speed up the cooling.

Instructions for Report Statement No. 6. After completing this experiment and studying the discussion, read Report Statement No. 6 carefully, then place a check mark in the box following *the correct method of making a temporary soldered connection to a soldering lug.* Copy your answer onto the last page of this Manual.

Report Statement No. 6: In a *temporary* soldered connection to a soldering lug, the wire is: *threaded twice through the hole in the lug* ☐; *hooked through the hole in the lug and squeezed before soldering* ☐; *hooked through the hole in the lug but not squeezed* ☒.

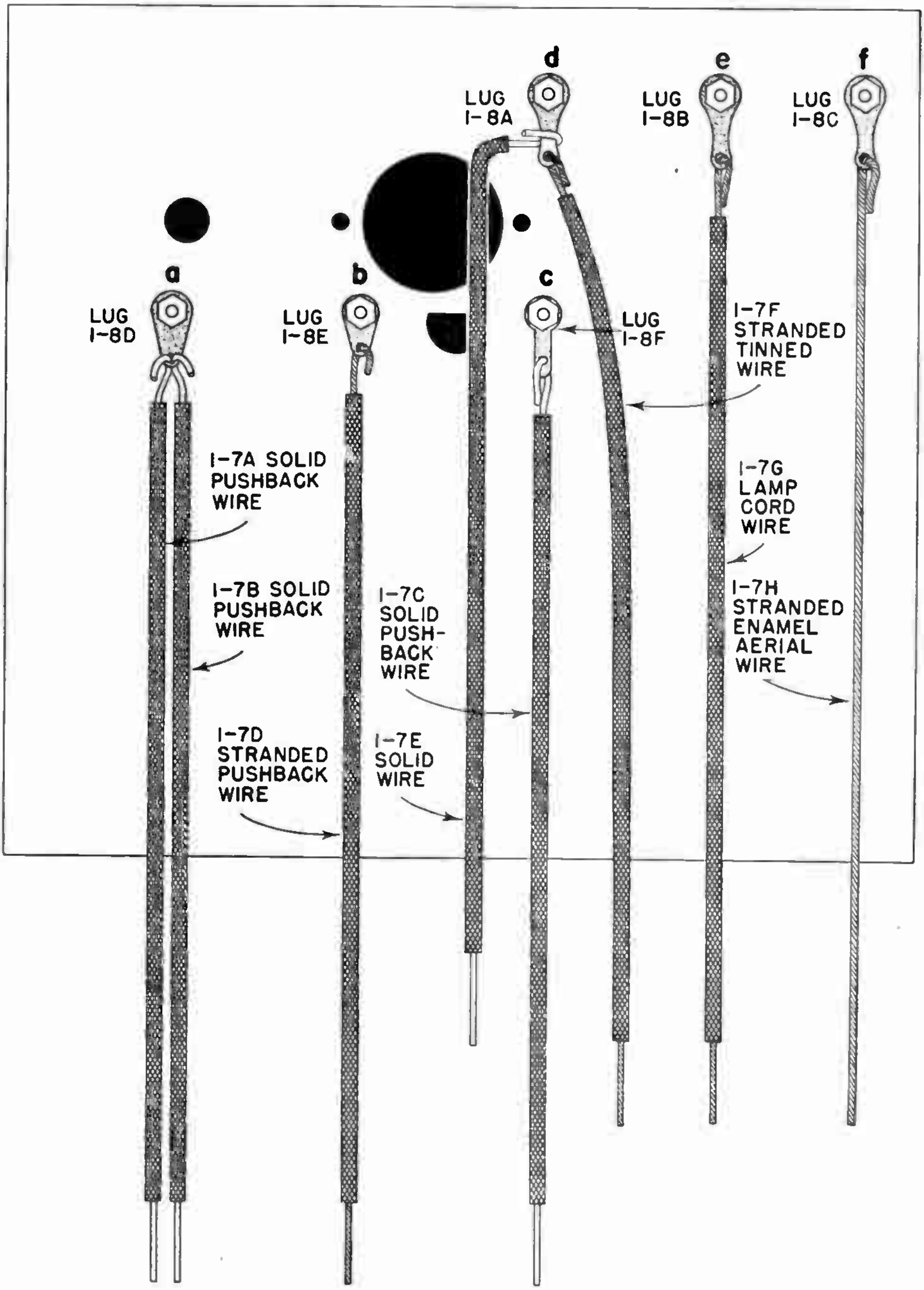


FIG. 30. Appearance of bottom of chassis after completion of Experiment 6. The actual soldering, of course, is not shown here. Each of the soldering lug connections commonly used by radio men is included in this experiment.

EXPERIMENT 7

Purpose: **To secure practical experience in soldering two wires together temporarily and permanently.**

Step 1. To make a temporary hook joint between two wires, locate wire 1-7B and wire *1-7E* on the chassis (by referring to Fig. *30)* and bend a hook in the free end of each with long-nose pliers. Hook together the free ends of the two wires as indicated in Fig. *31A*. If you first spread out the two wires, they will not fall apart when hooked together. Hold the heated soldering iron on one side of the joint for a few seconds, then apply rosin-core solder to the wires, starting at the soldering iron and then moving the solder away from it along the wires (see Fig. *31A)*. Remove the solder and the iron, and allow the joint to cool without disturbing it. The completed joint should resemble that shown in Figs. *31B* and *37*.

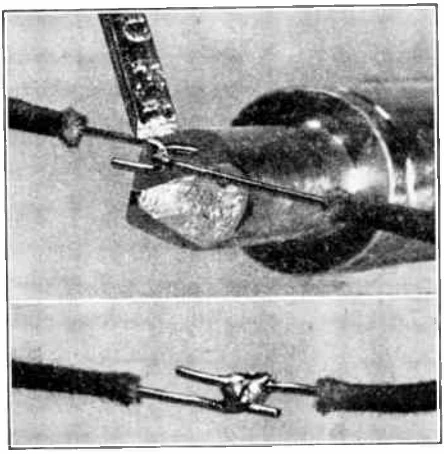


FIG. 31A (above). Correct way to solder a temporary hook joint. The tip of the iron is held under the joint, and the solder is applied to the wire from above.
FIG. 31B (below). Completely soldered temporary hook joint. Note that the hooks are *not* closed.

Step 2. To connect together two wires by means of a professional Western Union splice, locate wire *1-7A* and wire *1-7C*, and push back the insulation far enough to expose at least 1½ inches of wire at each free end (if the insulation cannot readily be pushed back this amount, remove the required amount of insulation by squeezing with pliers or by cutting with a pocket knife).

Grasp wire *1-7A* in your left hand, grasp wire *1-7C* in your right hand, and cross them in the manner shown in Fig. *32A*. The wires and the positions of the hands in this illustration are exactly as you would see them when looking at your work. Observe that wire *1-7A* is between you and wire *1-7C*.

Holding both wires between the thumb and forefinger of your right hand as shown in Fig. *32B*, twist the end of wire *1-7C* around the other wire with the thumb and forefinger of your left hand. Leave a little space between the turns so solder will flow readily between the wires. Continue twisting until only about ¼ inch of wire *1-7C* is left.

Now grasp the twisted part in your left hand and proceed to twist the free end of wire *1-7A* over the other wire in the *opposite* direction with your right hand, as illustrated in Fig. *32C*. Again allow about ¼ inch of wire to remain untwisted, so that the splice appears as shown in Fig. *32D*.

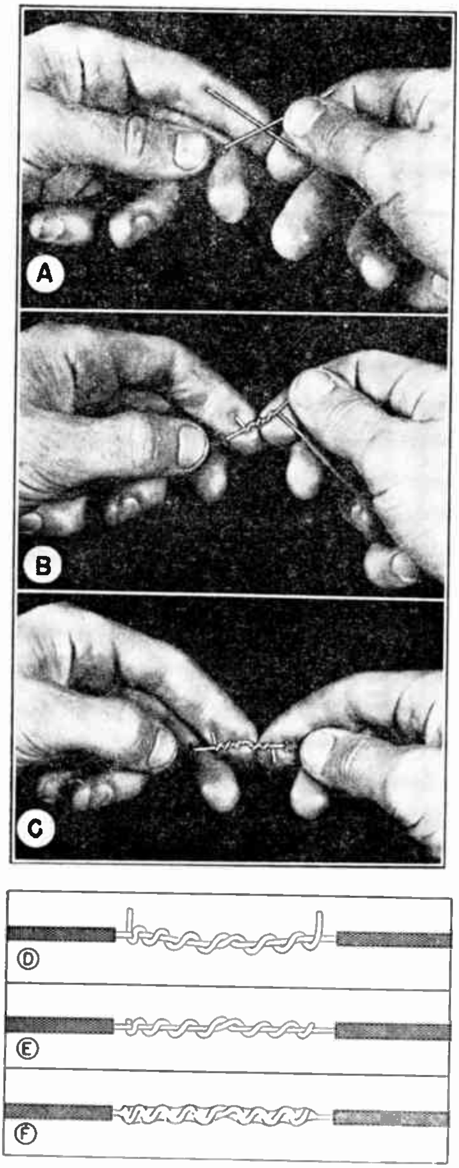


FIG. 32. Steps in connecting two wires together permanently by means of a Western Union soldered splice.

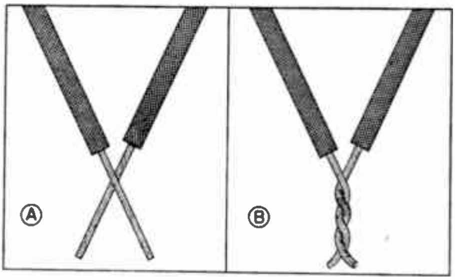


FIG. 33. Steps in making a common twist splice. This permanent joint is also known as a *Bell splice,* since it is used extensively by Bell Telephone linemen and switchboard men for connecting telephone wires together. When making this joint with solid wire, remove insulation for about 1½ inches from the end of each wire, twist up to about ¼ inch from the ends, solder the joint securely, then cut off the surplus wire with your side-cutting pliers.

Cut off the projecting ends of the wires with your side-cutting pliers, and straighten up the splice with the fingers so that it appears as shown in Fig. *32E*. Now hold the heated soldering iron alongside the splice just as you did in Step 1, and apply rosin-core solder first between the splice and the tip of the iron, then over all parts of the splice. Slide both the solder and the soldering iron along the splice to speed up the process, until the entire twisted portion of the splice is covered with solder. The completed splice should appear as shown in Fig. *32F*.

Step 3. To connect two wires together by means of a permanent Bell splice, locate stranded wire *1-7F* and the stranded lamp cord wire *1-7G* on the chassis, cross the bare end of the wires as shown in Fig. *33A,* then proceed to twist the wires together *with the fingers* so that the result appears as shown in Fig. *33B*. Cut off about 1/16 inch from the end of the splice with side-cutting pliers to give a neat joint, then solder the splice as instructed in Step 1.

Step 4. To make a permanent T type joint to some point on wire *1-7C*, take your pocket knife and cut through the insulation at a point near the center of this wire, being careful not to damage the wire itself. Now push the insulation apart at this point so as to expose about 1 inch of wire. (Do not discard the wire if you accidentally nick it, for the soldered joint will bridge across the nick in the wire.) Take the stranded wire *1-7D*, shorten it as shown in Fig. *37* by winding the wire a few times around a pencil, then twist together the strands at its free end, and wind this end around wire *1-7C* with your fingers. Space the turns apart a small amount as shown in Fig. *34*. Trim off the ends of the strands with side-cutting pliers, then solder the joint as instructed in Step 1. Now push the insulation on wire *1-7C* up to this T joint on both sides.

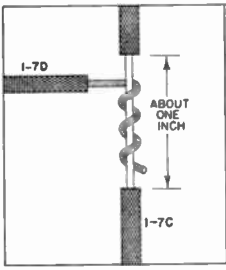


FIG. 34. Permanent T type joint between two insulated wires.

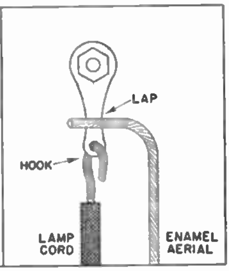


FIG. 35. Temporary lap joint on top of a soldering lug.

Step 5. To make a temporary lap joint between one wire and a lug or between two wires, take enameled wire *1-7H* and apply additional solder to its free end by employing the same technique used for tinning solid wires. Next, apply a small amount of solder to the top of lug *1-8B*, just behind the joint already on this lug. Now hold the free end of the wire over the lug just behind the joint, as shown in Fig. *35*, press your heated soldering iron over rosin-core solder so it will pick up some solder on its lower face, then apply the soldering iron to the top of wire *1-7H* so as to fuse together the solder on the wire and the solder on the lug. Remove the soldering iron when fusion occurs, but continue holding wire *1-7H* rigid until the solder has hardened. The completed joint is shown in Fig. *37*.

Discussion: Radio servicemen probably use the temporary hook joint more often than any other joint for connecting together two wires. The reason is simply that this joint can be unsoldered and separated very easily. The joint can be made more permanent, yet still be unsoldered fairly easily, by squeezing the two hooks together with long-nosed pliers just before soldering.

As a general rule, a joint between two wires should always be covered with friction tape when left permanently in a radio receiver. Radio men prefer to use a special narrow type of friction tape, obtainable in ⅜-inch wide rolls at radio supply houses, for the standard ¾-inch tape is awkward to use on small joints.

When a joint is taped, all exposed wires are covered with at least two thicknesses of the friction tape, and the surrounding insulation is also covered with friction tape for about ½ inch on each side of the joint. Typical taped joints are shown in Fig. *36*.

Figure *37* is presented for reference purposes, to show you how your chassis should look after completing this experiment. Whenever you are in doubt as to the position in which a particular joint is to be made, refer to this illustration.

The hook joint is not suitable for use where considerable force may be applied to the wires. The Western Union splice described in Step 2 is preferred by radio men when mechanical strength is required. Telegraph lines on poles are joined together by means of this splice.

The Bell splice described in Step 3 is usually easier to make in a crowded radio chassis than is the Western Union splice. When made with stranded wire, the Bell splice is readily formed with the fingers; with solid wire, it can either be twisted with the fingers up to about ¼ inch from the end, and the surplus wire then cut off, or the twisting can be completed with long-nosed pliers. Study the illustrations carefully, to determine just how much of a twist each type of splice should have.

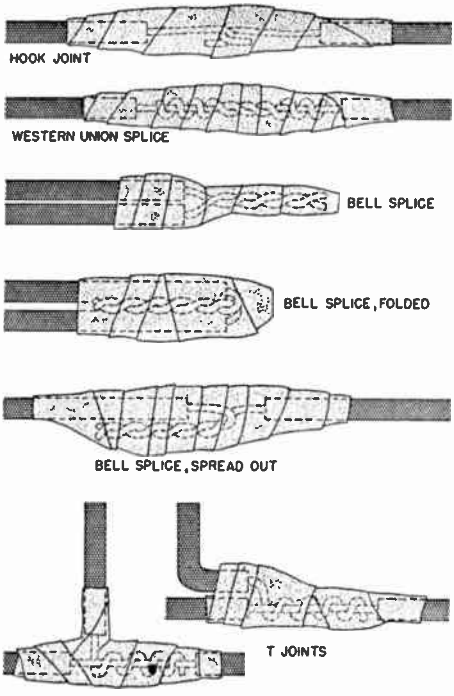


FIG. 36. Methods of taping the various types of soldered joints taken up in this manual. These diagrams are presented for future reference only, since you do not have to tape any of the joints used in your Practical Demonstration Course.

The permanent T joint described in Step 4 is occasionally required in radio work, for it permits connecting one wire to any point along another wire. The important factor in this joint is the removal of the insulation along the wire without damaging the wire itself. With push-back wire, only a single cut need be made, for the insulation can then be pushed apart. With other types of insulation, however, the insulation must be sliced off carefully with a knife, or squeezed with pliers and then trimmed off.

The temporary lap joint covered in Step 5 is widely used by radio men for test purposes. You will use it extensively in future experiments in your demonstration course. This joint can be made just as well to another soldered connection or to a wire; it was made to a soldering lug in this step merely for convenience. The secrets of a good lap joint are applying the solder to the individual parts *before* placing them together, and holding the wire perfectly rigid while the solder is hardening.

In soldering any joint, first make a secure mechanical connection, and then be sure that the solder flows in between the turns or twists of the wire. If the wire has previously been tinned properly, there should be no difficulty in accomplishing this.

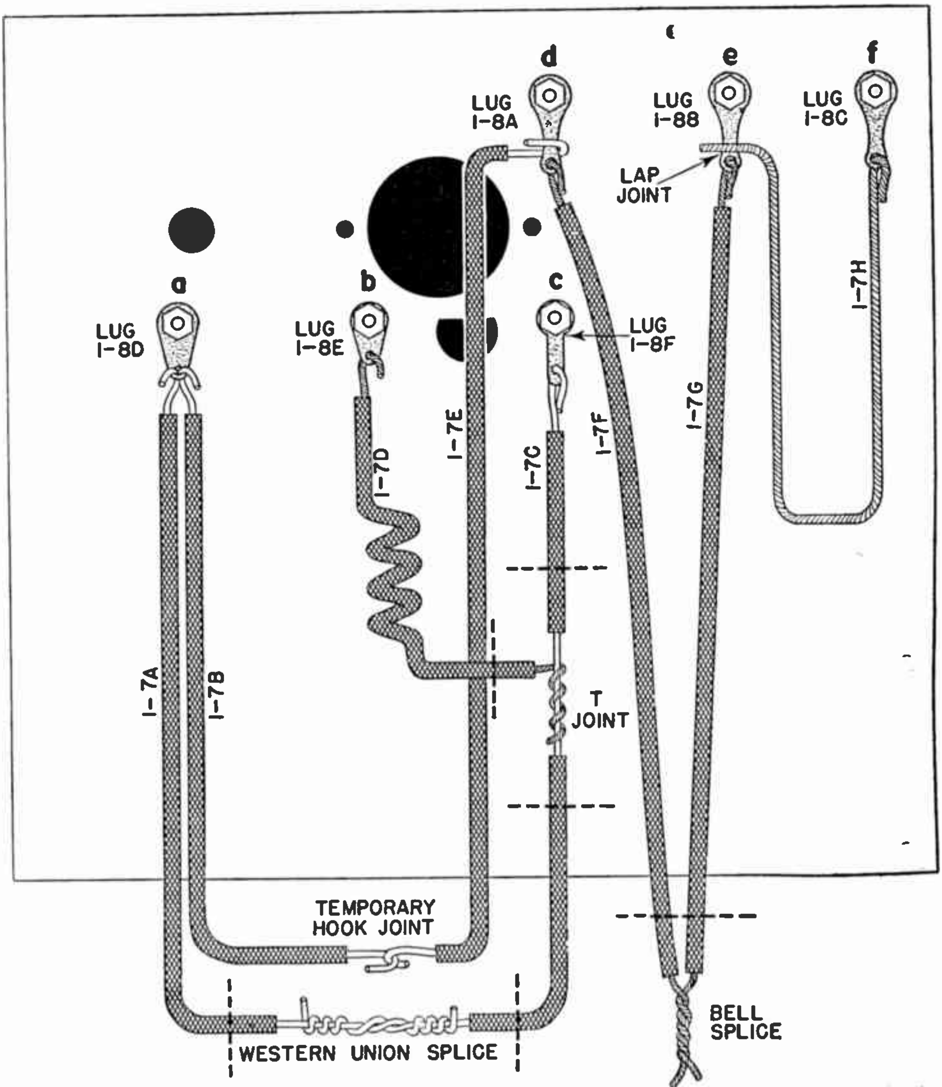


FIG. 37. Your chassis should appear like this after you have completed each of the joints called for in this experiment. The dotted lines indicate the approximate positions at which cuts should be made to remove the splices after completing the experiment.

Any connection which depends upon solder for adequate mechanical strength and electrical conductivity is known as a *joint*. A connection between two wires which gives adequate mechanical strength and electrical conductivity initially without solder is known as a *splice*. Solder is used on a true splice chiefly to prevent corrosion with age from affecting the original electrical conductivity.

The only two splices which are used to any extent in radio work are the Western Union splice and the Bell splice, both of which you made in this experiment. All other radio connections can be considered as joints. You thus see that the great majority of joints made by professional radio men require soldering for effectiveness.

Instructions for Report Statement No. 7. After completing this experiment and studying the discussion read Report Statement No. 7 carefully, then place a check mark in the box following the answer which you believe *will give the greatest mechanical strength,* when used to connect wires together end to end. Copy your answer onto the last page of the Manual.

Report Statement No. 7: When connecting two wires together where great mechanical strength is required, I would use a: *lap joint* ☐; *Bell splice* ☐; *Western Union splice* ☒; *hook joint* ☐.

EXPERIMENT 8

Purpose: **To secure experience in unsoldering the various types of temporary and permanent connections encountered in radio work.**

Step 1. To secure experience in disconnecting splices and permanent joints between two wires, try unsoldering the Western Union splice by any means you desire. Yes, this joint is very difficult to unsolder; in fact, radio men never bother unsoldering it. Therefore, proceed to cut out this joint with your side-cutting pliers as indicated by the dotted lines in Fig. *37*. Try also to unsolder the Bell splice. It, too, is difficult to unsolder. Cut it out of the lead as you did the Western Union splice. Finally, cut out the T joint by making three cuts with your side-cutting pliers as indicated by the dotted lines in Fig. *37*.

Step 2. To secure experience in unsoldering temporary joints, unsolder the temporary hook joint between wire *1-7B* and wire *1-7E*, by applying the heated soldering iron to the joint and unhooking the wires as soon as the solder has melted. Using this same procedure of holding the soldering iron against a joint to melt the solder, proceed to unhook the wires from *lugs 1-8D* and *1-8E*. Next, unsolder the lap joint on *lug 1-8B*.

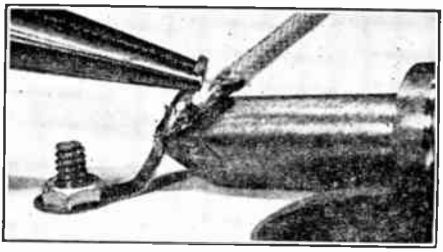


FIG. 38. Method of unsoldering a permanent hook joint on a soldered lug. Spread open the hook with long-nose pliers while keeping the solder molten by holding the soldering iron under the lug.

Step 3. To secure experience in unsoldering permanent joints, hold your heated soldering iron in one hand and apply it to lug *1-8A* while pulling open the hook at the end of wire *1-7E* with your long-nose pliers. Slide the wire off the lug as soon as the hook has opened sufficiently for this purpose.

Now open the hook in wire *1-7F* (on this same lug) with long-nose pliers while heating with the soldering iron, and unhook the wire. Be sure to save this wire, because it is a specially insulated wire which you will need later. This professional unsoldering procedure is illustrated in Fig. *38*.

To practice the technique employed by radio men for unsoldering wires which are difficult to bend open, melt the solder on lug *1-8B* with the soldering iron, then wiggle the *1-7G* lamp cord vigorously while the wire is cooling. Spread out the hook as much as possible with long-nose pliers after the joint has cooled, then repeat the heating and wiggling procedure until the wire is separated from the lug.

Use this same wiggling and unbending procedure for enamel wire *1-7H* on *lug 1-8C* and for wire *1-7C* on *lug 1-8F*.

Finally, lift off surplus solder from the lugs on the chassis with the cleaned, heated soldering iron, as instructed in Step 4 of Experiment 5. When there is a great deal of solder on a lug, you can speed up this step by holding the soldering iron tip alongside or under the lug so as to keep the solder molten, and wiping off this solder with quick strokes of a cloth.

Discussion: As you learned by actual trial in Step 1, it is very difficult to unsolder a properly formed splice. In an emergency, you could untwist the splice bit by bit with long-nose pliers while keeping the solder molten with the soldering iron, but this tedious procedure is required only when the wires must be used again and would be too short if cut off. The Radiotrician invariably snips off splices and T joints with the side-cutting pliers, just as you did in this step.

Step 2 demonstrated to you that a temporary soldered joint can be disconnected simply by applying the heated soldering iron to melt the solder, then unhooking the joint. Only when working in awkward and crowded positions is it necessary to spread apart the hook in a temporary joint. Lap joints are the easiest to unsolder of all joints.

When working on radio receivers, most of the joints which you unsolder will be of the type you practiced with in Step 3. These invariably must be spread apart with long-nose pliers before the wire can be unhooked from the lug. Sometimes it will be necessary to remove surplus solder from the joint before you can grip the end of the wire with long-nose pliers.

During unsoldering, surplus solder will accumulate on the soldering iron. Shake this off from time to time, but remember that a *little* extra solder on the iron will speed up transfer of heat to the joint being unsoldered. Sliding the soldering iron back and forth a bit over the joint also speeds up unsoldering, for this tends to break through the coating of oxide and dirt on old solder.

Instructions for Report Statement No. 8. After completing this experiment and studying the discussion, read Report Statement No. 8 carefully, then place a check mark in the box following *the type of joint which you found easiest to unsolder* when you unsoldered these *three* joints in Steps 2 and 3. Copy your answer onto the last page.

Report Statement No. 8: I found it easiest to unsolder a: *lap joint* ☒; *temporary hook joint to a lug* ☐; *permanent hook joint to a lug* ☐.

EXPERIMENT 9

Purpose: **To secure practical experience in connecting actual radio parts to soldering lugs by means of temporary and permanent soldered connections just as you would do when servicing radio receivers.**

Step 1. To mount the tube socket (Part *1-10) on the chassis* in preparation for this experiment, take one machine screw (Part *1-9A)* and insert it in hole *h* (Fig *39) from the top* of the chassis. Holding one finger on the head of this screw to keep it in the hole, turn the chassis over and place the tube socket in position in the manner illustrated in Fig. *39,* so that the aligning slot in the center hole of the socket is next to this screw. After pushing the metal mounting flange of the socket over the screw, place a hexagonal nut (Part *1-9B*) on the screw and tighten partially with the fingers. Now take another machine screw, insert it through hole *i* from the top of the chassis and through the other mounting hole of the tube socket, then place a hexagonal nut on this screw. Hold this nut with long-nose pliers, then tighten the screw from the other side of the chassis with a medium-sized screwdriver. Tighten the other socket mounting screw in the same manner.

The tube socket has six terminal lugs, each identified by a number molded into the Bakelite base alongside the lug. The numbers are *2, 3, 4, 5, 6,* and *7*. To speed up future work on this socket, take a crayon or pencil and mark the number of each lug clearly, directly alongside the lug on the bottom of the chassis. The portion of the chassis on which you will work in this experiment should now appear as shown in Fig. *40*.

Step 2. To connect a condenser temporarily between two soldering lugs, take the .05-mfd. condenser (Part *1-13)* and bend an open hook in the end of each lead with long-nose pliers. Bend the condenser leads with your fingers approximately to the shape shown for Part *1-13* in Fig. *41*. Now hook the condenser leads into the holes in lugs *1-8C* and *1-8E* from the bottom and allow the condenser to rest on the chassis, as in Fig. *41*.

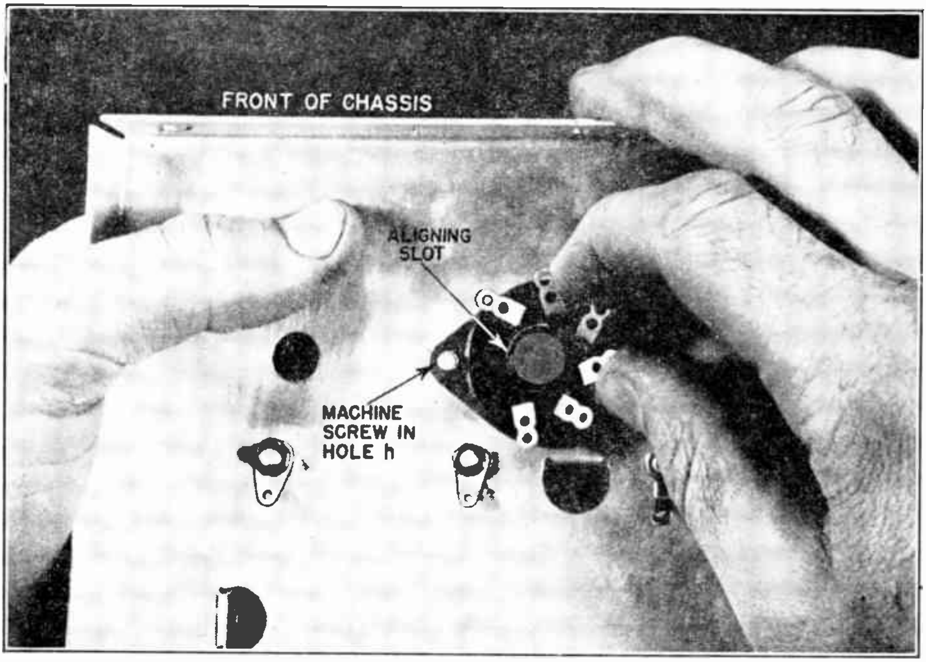


FIG. 39. Method of mounting the tube socket on the chassis. The terminal lugs of the socket should be underneath the chassis, and the aligning slot should be at the left (near hole *h*) when the chassis is held as shown in this illustration. Hold the machine screw in position with a finger of your left hand.

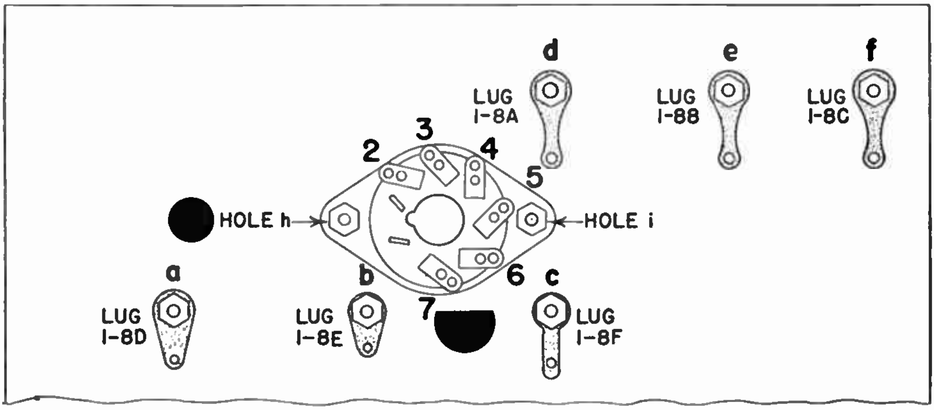


FIG. 40. Your chassis should appear exactly like this after you complete Step 1 in Experiment 9. Note that the socket has been fastened to the *under* side of the chassis.

Solder each condenser lead by applying the heated soldering iron to the top of the lug on one side of the wire, and applying rosin-core solder to the other side of the wire and to the lug.

IMPORTANT: The soldering iron tip must make good contact with both the lug and the wire, so as to heat and solder both parts of the joint.

Step 3. To connect a condenser permanently between two lugs of a tube socket, take the .03 mfd. condenser (Part *1-12),* bend an open hook in the end of each lead, then bend the leads themselves approximately to the shapes indicated for Part *1-12* in Fig. *41*. Hook the condenser leads through the outermost holes in lugs *2* and *7* of the tube socket, by inserting the ends of the leads through the holes in the lugs from underneath, and squeeze each hook together with long-nose pliers, as indicated in Fig. *41*.

Solder the condenser lead which is on lug *7* of the tube socket. Leave the lead on lug *2* unsoldered.

Step 4. To connect a resistor temporarily between two lugs, take the .1-megohm resistor (Part *1-15*) and bend a hook in the end of one lead with long-nose pliers. With your fingers, bend the leads for this resistor approximately as indicated for Part *1-15* in Fig. *41*, then insert the hook into the outermost hole in socket lug *4* from underneath. Push the other resistor lead into the hole in soldering lug *1-8B* from above, then bend the end of the lead up with long-nose pliers to form a hook, as shown on lug *1-8B* in Fig. *41*. Now solder both of the joints for resistor *1-15*.

In the same manner, bend one lead of 18,000-ohm resistor *1-16* into a hook and insert it in lug *1-8D* from underneath as indicated in Fig. *41*, then bend the other lead (as shown in the illustration), push it through the outermost hole in tube socket lug *6* from underneath, then bend the end of the lead back with long-nose pliers to form a hook. Solder both of the joints now for resistor *1-16*.

Step 5. To connect a resistor permanently between two tube socket lugs, take .24-megohm resistor *1-14*, bend its leads approximately as shown in Fig. *41*, form a hook in the end of each lead, then hook the leads through the holes in tube socket lugs *2* and *3* from underneath. This places two leads in lug *2*. If you have difficulty

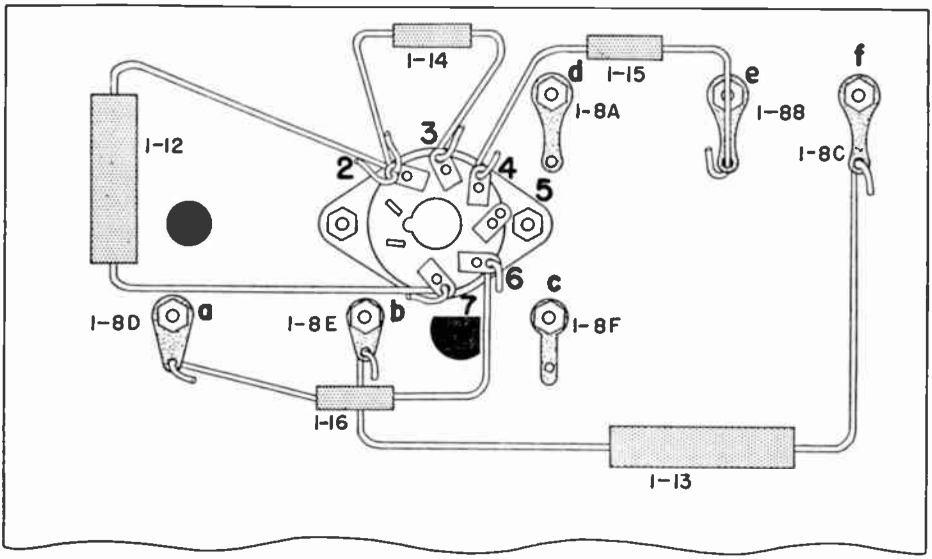


FIG. 41. The five radio parts which you connect to lugs in Experiment 9 are shown here ready for soldering. If you prefer, you can prepare all the parts in this manner, and then solder all the joints at once instead of soldering each part separately as called for in the experiment. WARNING: Bends in resistor and condenser leads should be *gradual* (not sharp), and should begin at least one-quarter inch away from the body of the part; otherwise, the leads will break off.

in inserting the lead in the outermost hole of tube socket lug *2* even though this lug has not yet been soldered, use the other hole in this lug. Squeeze the hooks together tightly with long-nose pliers, then proceed to solder lugs *2* and *3*.

Discussion: With radio parts like the condensers and resistors included in this radio Kit, the bending of the leads to their proper shapes is an important part of the connecting process. Do not intentionally make sharp-cornered bends in leads by means of pliers, however, for this may weaken the wire. Make the bends with your fingers, and use pliers only when forming hooks in the ends of wires. Bends in leads should always start at least ¼ inch away from a resistor or condenser for the same reason.

Bend each lead carefully, checking your work continually by fitting the leads to the correct lugs on the chassis. Additional bending may be done after the leads have been soldered; in fact, the leads should always be bent away from the chassis after this is done, to minimize the possibility of bare wires shorting to the chassis. The leads to these condensers and resistors are stiff enough to support the parts in air.

A permanent joint differs from a temporary joint only in the squeezing of the hook with long-nose pliers prior to soldering. The ends of permanent hook joints should be cut off after the joint has been soldered and allowed to cool, so that accidental short-circuits and grounds cannot occur. You will find that this little extra step makes a great deal of difference as regards the ease with which a joint can be unsoldered.

In this experiment, you have connected radio parts exactly as they would be connected by professional radio servicemen. With the repeated practice in soldering which you will secure in future experiments, you will soon find yourself able to make soldered connections with professional skill, speed, and efficiency.

Instructions for Report Statement No. 9. After completing this experiment and studying the discussion, read Report Statement No. 9 carefully, then place a check mark in the box following *the splice or joint which is most often used in radio work for connecting the leads or radio parts to soldering lugs.* Then copy your answer onto the last page of the Manual.

Report Statement No. 9: The leads of radio parts are usually connected to soldering lugs by means of: *Western Union splices* ☐; *Bell splices* ☐; *hook joints* ☒.

EXPERIMENT 10

Purpose: **To secure experience in unsoldering connections like those encountered in radio receivers, just as you would do when removing a defective part from a receiver.**

Step 1. To remove .1-megohm resistor 1-15 from your chassis, apply the heated soldering iron to one side of lug *1-8B*, unbend the hook with long-nose pliers while the solder is molten, then pull this lead out of the lug by pulling on the lead with long-nose pliers. Now apply the soldering iron to tube socket lug *4*, and unhook the other resistor lead from this lug.

Step 2. To remove 18,000-ohm resistor 1-16 from your chassis, use your long-nose pliers to open up the hook in lug *1-8D* while applying the soldering iron to this lug so as to melt the solder. When the end of the lead is straight up and down, pull the wire out of the hole in the lug with your long-nose pliers while keeping the solder molten with the soldering iron. Now apply the soldering iron to lug *6*, and unhook the resistor lead going to this lug.

Step 3. To remove .05-mfd. condenser 1-13 from your chassis, apply the soldering iron to lug *1-8E* while grasping with long-nose pliers the lead going to this lug. Unhook the lead from this lug. This will undoubtedly cause bends in both condenser leads, but you can readily straighten these out after the part has been removed. Now melt the solder on lug *1-8C*, and unhook the lead from this lug in the same manner.

Step 4. To remove .03-mfd. condenser 1-12 and .24-megohm resistor 1-14 from your chassis, first apply the heated soldering iron to lug *7*, and pry open the hook in the condenser lead going to this lug. Do not expect to do this in one trial, for it is usually quite difficult to get a good grip upon the end of the wire with pliers. Continue unbending the hook until you can push the wire out of the lug. The other lead of this condenser will be somewhat more difficult to unsolder, since it goes to a lug *(2)* which has two connections; use exactly the same technique, however.

Part *1-14* also has permanent connections, so unsolder its leads from lugs *2* and *3* in the same manner.

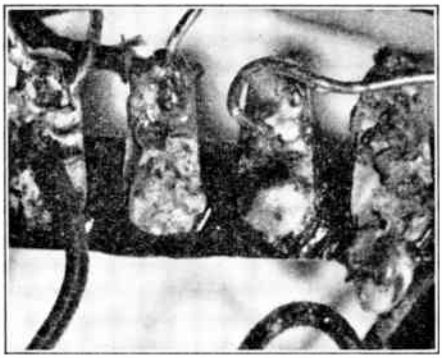
Step 5. Remove surplus solder from all six soldering lugs and from the lugs on the tube socket, either by wiping off the molten solder with a cloth or by lifting it off with the clean soldering iron. Melt and shake off surplus solder from the leads of the five radio parts used in this experiment, then straighten out the leads with your fingers as well as you can. If the ends of any leads have been damaged by the long-nose pliers, cut off about ¼ inch from each end.

Simply straighten out the hooks in the remaining leads if the wires themselves are in good condition, so that all parts are clean and ready for use again in future experiments. Now remove the six soldering lugs *(1-8A, 1-8B, 1-8C, 1-8D, 1-8E,* and *1-8F)* and the six screws and nuts from the chassis with your screwdriver and long-nose pliers, then set aside the lugs, screws, and nuts for future use. Leave the tube socket on the chassis.

Discussion: In this experiment, you demonstrated for yourself the fact that hook joints which are not squeezed prior to soldering are fairly easy to unsolder. You found that sometimes the leads can be removed from a lug without unbending the hook, while in other cases it was necessary to unbend the hook somewhat with long-nose pliers before the lead could be pulled away from the lug.

You also found that permanent soldered connections can be unsoldered fairly easily once you get the knack of prying open the hook with long-nose pliers. As you undoubtedly realize now, it is quite a trick to hold a heated soldering iron against one part of a lug while prying open a wire on that lug with long-nose pliers. You will become quite proficient in this work, however, by the time you have completed your home demonstration course.

Whenever a permanent hook joint has been squeezed so tightly that it is very difficult to get a grip on the end of the wire with long-nose pliers, servicemen will usually snip off the wire as close as possible to the soldering lug with side-cutting pliers. The portion of the wire remaining in the lug can either be pushed out with the tip of the soldering iron after this is done, or can be cut again with side-cutting pliers so it will fall out when the soldering iron is applied. You may use this procedure if you have difficulty in unsoldering any of the joints.



An example of poor soldering. The lumpy, cracked appearance shows too much solder was used and the joints were not heated enough.

Sometimes the wire will come out after only a part of the hook is cut off. Then again, it may be possible to spread the hook apart with a small screwdriver or with the blade of a pocket knife.

Instructions for Report Statement No. 10. After completing this experiment and studying the discussion, read Report Statement No. 10 carefully. Place a check mark in the box following the statement that describes the condition of the solder which makes it easier to disconnect a permanent hook joint. Then copy your answer onto the last page of the Manual.

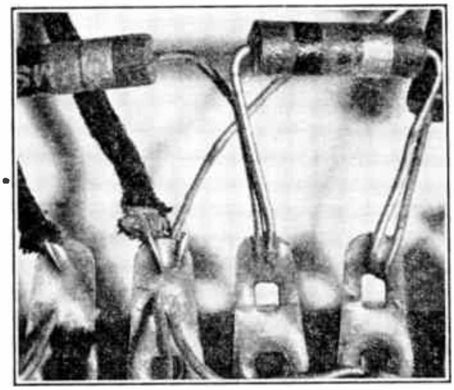
Report Statement No. 10: When disconnecting a permanent soldered hook joint, the hook is easier to pry open with long-nose pliers while the solder is: *hard* ☐; *molten* ☒.

Requirements of a Good Soldered Joint

The seven important requirements of a good soldered radio joint are reviewed in convenient reference form in Fig. 42. If you understand and follow each of these requirements, you should have no difficulty in making professional soldered joints once you have practiced as instructed in your home demonstration course.

In the case of plain soldering irons, which must be heated by an alcohol burner, we have the additional requirement that the soldering iron be at the correct temperature. (This requirement is taken care of automatically in an electric soldering iron by the original design of the heating element.) If the soldering iron is too cold, a joint made with it may look good but be mechanically and electrically weak because hardened rosin is the chief bonding material. The resulting "rosin" joint (one in which there is little or no solder connecting the two parts together) is unsatisfactory and can actually be an open connection. In any event, a rosin joint will eventually break apart and cause trouble.

Too hot a soldering iron is equally unsatisfactory, for excessive heat will evaporate the rosin flux before it has a chance to act upon the work, and will make the solder flow too rapidly away from the joint. Furthermore, excessive heat will travel around the joint through the copper wire and burn insulation or loosen adjacent soldered joints.



Good soldering produces a smooth, even coating of solder. The joints have been heated sufficiently to melt the solder and just enough solder has been used to coat the joint thinly.

Looking Forward

Having mastered professional soldering techniques, you are ready to set up real radio circuits with soldered joints, and demonstrate basic radio principles for yourself. In your next

REQUIREMENTS OF A GOOD SOLDERED JOINT

1. KEEP YOUR SOLDERING IRON CLEAN AND WELL TINNED
2. REMOVE INSULATION FROM WIRES, AND SCRAPE OFF EXCESSIVE DIRT. AVOID NICKING THE WIRE WITH THE SCRAPING TOOL
3. USE ONLY ROSIN-CORE SOLDER FOR RADIO WORK.
4. TIN EACH PART SEPARATELY IF ORIGINALLY UNTINNED.
5. MAKE GOOD MECHANICAL CONTACT BETWEEN THE PARTS BEING SOLDERED
6. APPLY THE SOLDER TO THE LUG OR WIRE, NOT TO THE SOLDERING IRON.
7. DO NOT MOVE THE JOINT UNTIL THE SOLDER HARDENS.

FIG. 42. Observance of these seven basic requirements is the secret of making professional soldered joints for radio equipment.

radio Kit will be another fascinating collection of actual radio parts, including a milliammeter and a vacuum tube. With these additional parts you will assemble simple electrical and radio circuits and trace electron flow through them. You will make measurements of current and voltage in these circuits, and see for yourself that current, voltage, and resistance in a circuit always have values which agree with Ohm's Law.

Finally, after completing Experiment 20, you will assemble the NRI Tester on its attractively designed panel and chassis. This is a specially designed measuring instrument which is equivalent to eighteen separate ordinary meters. You will use the NRI Tester a great deal in future experiments.

IMPORTANT

Be sure to save ALL PARTS from this Radio Kit, including the soldering lugs, screws, and nuts, because you will need them later. Keep small parts in individual envelopes or boxes.

Detach by Cutting At [illegible] Line. Do Not Tear off.