INSTRUCTIONS FOR PERFORMING RADIO EXPERIMENTS 21 TO 30

3 RK-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

PIONEER HOME STUDY RADIO SCHOOL

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
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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

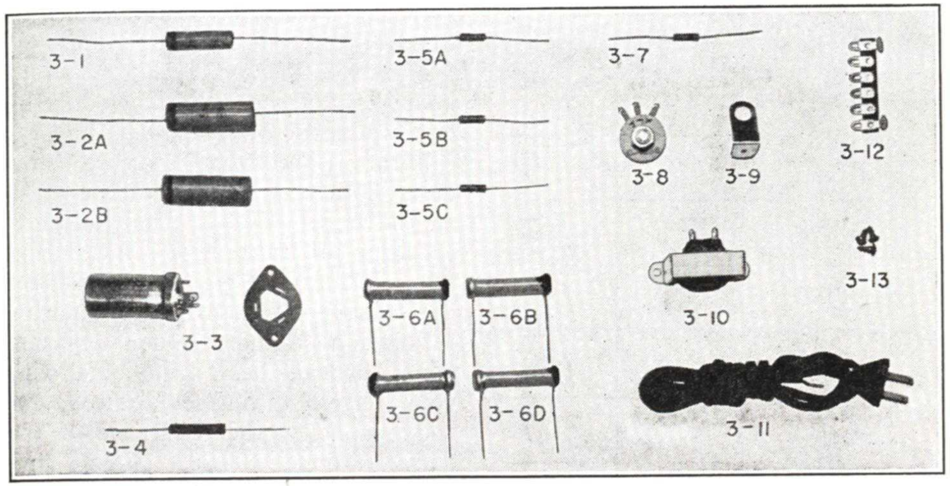


Fig. 1. The parts included in Radio Kit 3RK-1 are pictured above, and are identified in the list below. Some resistors may have a better tolerance (a lower percentage tolerance) than that indicated here.

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	1.5	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	6.0	6.0
5	VOLTAGE OF CELLS A+B+C−D	3.0	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	1.5	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
9	CELLS A,B,C AND D IN SERIES-PARALLEL		3.0
10	CELLS A,B,C AND D IN SERIES-PARALLEL		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 calibra-

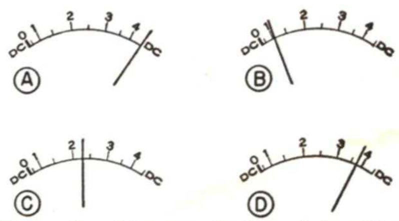


FIG. 2. Actual-size reproductions of the *DC* scale on the meter of the N.R.I. Tester, with examples showing how to read this scale at four different pointer positions. The readings are as follows: *A*—4.5; *B*—1.1; *C*—2.3; *D*—3.75.

tion shift yourself by removing the calibrating clip from the —9C battery terminal, touching it momentarily to a terminal 4½ volts less negative

* If you write to N.R.I. regarding this tester, please refer to it as the *N.R.I Tester for Experiments.*

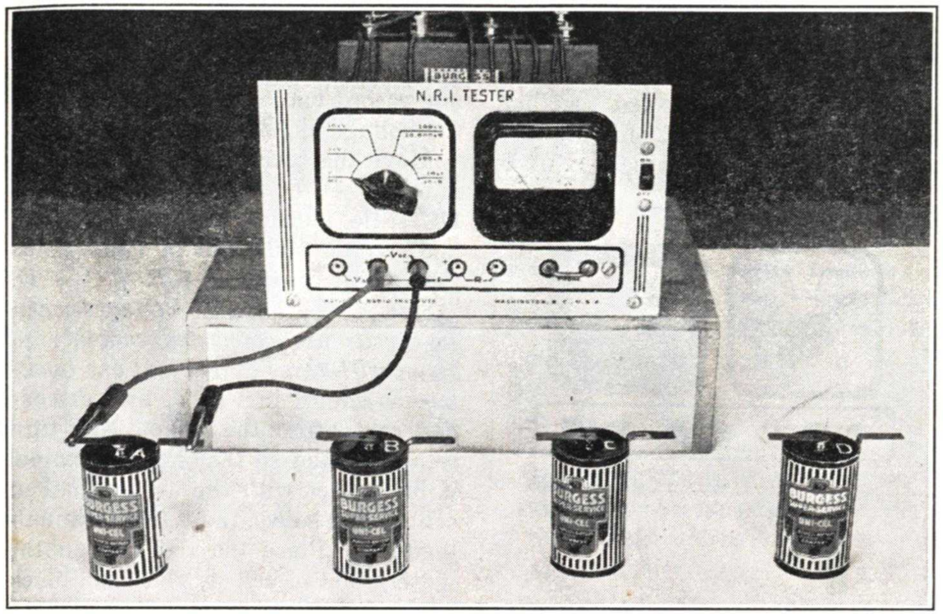


FIG. 3 Method of using the N.R.I. Tester to measure the voltage of individual dry cells. This set-up is used in Step 3 of Experiment 21. The test leads were shortened for this photograph in order to make them show more clearly, but *do not shorten your own test leads.* Placing the N.R.I. Tester on a 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

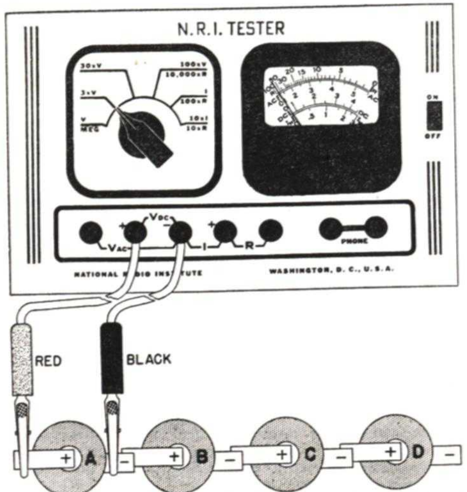


FIG. 4. This diagram illustrates how voltage measurements are made on a group of four flashlight cells connected in series-aiding for Step 4 of Experiment 21.

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.

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,

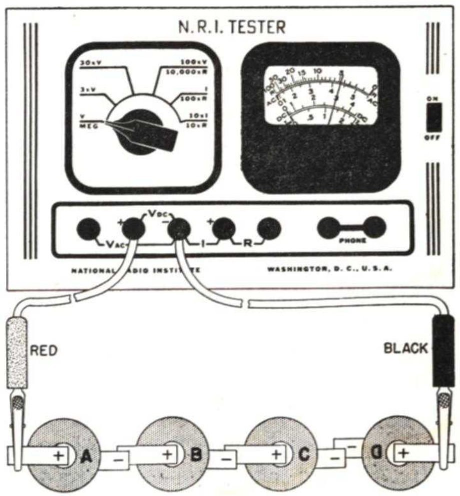


FIG. 5. Method of connecting four flashlight cells in series with three aiding and one bucking, with the *V* range of the N.R.I. Tester being used to check voltages. This measurement is made in Step 5 of Experiment 21.

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 $A + B + C - D$.

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

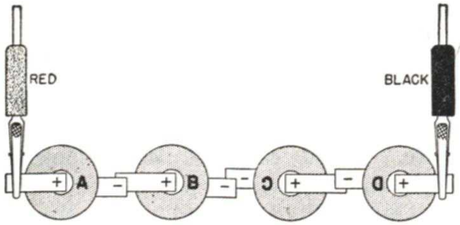


FIG. 6. Cell connections and test clip positions for Step 6 of Experiment 21.

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 $A + B - C - D$.

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

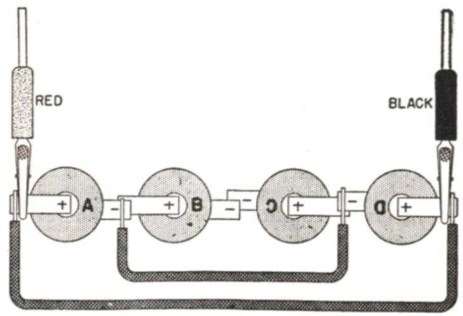


FIG. 7. Cell connections and test clip positions for Step 7 of Experiment 21.

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 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.

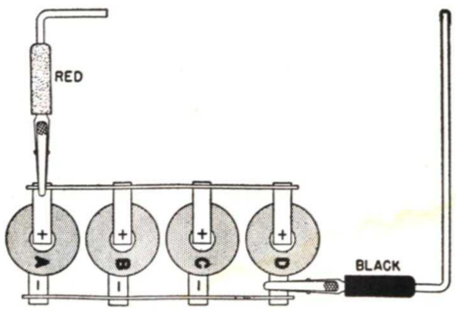


FIG. 8. Cell connections and test clip positions for Step 8 of Experiment 21.

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.

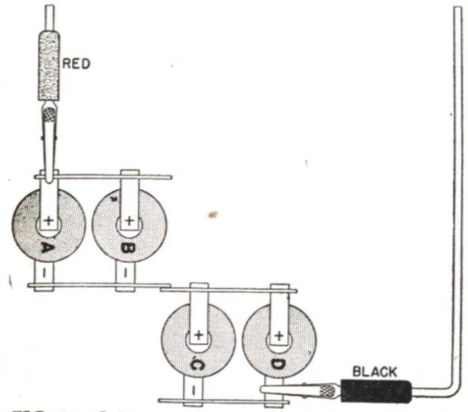


FIG. 9. Cell connections and test clip positions for Step 9 of Experiment 21, in which two parallel-connected pairs of dry cells are connected in series.

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.

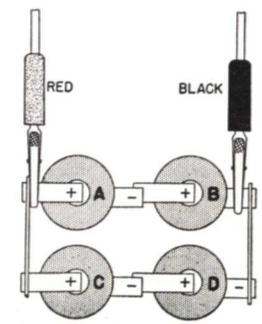


FIG. 10. Cell connections and test clip positions for Step 10 of Experiment 21, in which two series-connected pairs of dry cells are connected in parallel.

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.

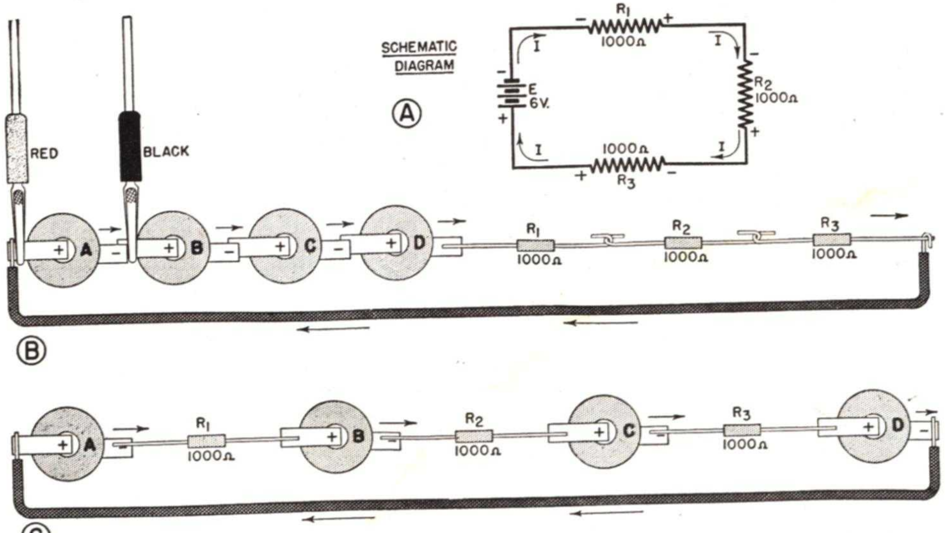


FIG. 11. Semi-pictorial and schemetic circuit diagrams for Experiment 22. Arrows indicate the direction of electron flow in each case.

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	A		+1.5
B		+1.5	R_1		-2.0
C		+1.5	B		+1.5
D		+1.5	R_2		-2.0
R_1		-2.0	C		+1.5
R_2		-2.0	R_3		-2.1
R_3		-2.1	D		+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 circuit toward the + terminal of the source. Since you know the direction 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

*$E = I \times R$; 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.

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.

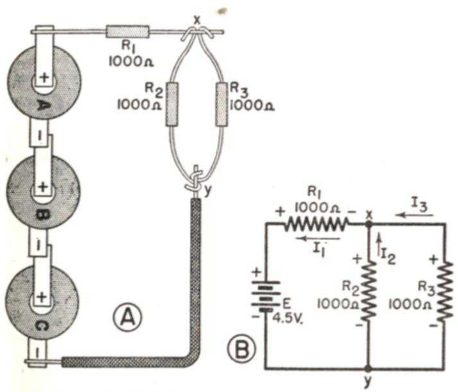


FIG. 12. Semi-pictorial and schematic circuit diagrams for Experiment 23.

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.)	-3.0	-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*.

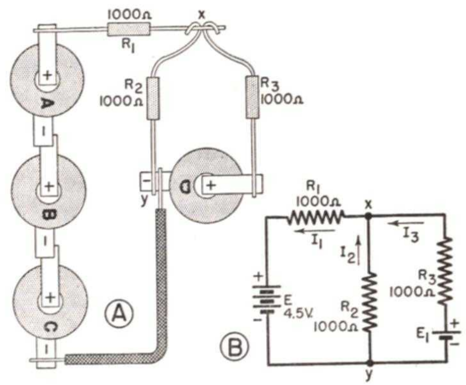


FIG. 13. Semi-pictorial and schematic circuit diagrams for Experiment 24.

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.

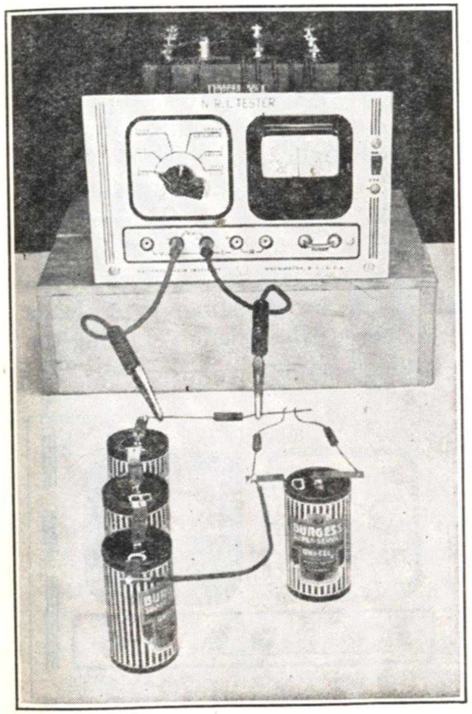


FIG. 13C. This photographic illustration shows the parts connected for Step 1 of Experiment 24, with the N.R.I. Tester connected to measure the voltage across R_1.

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 sec-

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.	5	6	5
2	DISCHARGING .5 MFD. THRU 10 MEG.	6	6	5
3	DISCHARGING .5 MFD. THRU .9 MEG.	LESS THAN 1 SEC.	less than 1 SEC.	.45

TABLE 25. Record your results here for Experiment 25.

onds 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.

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.

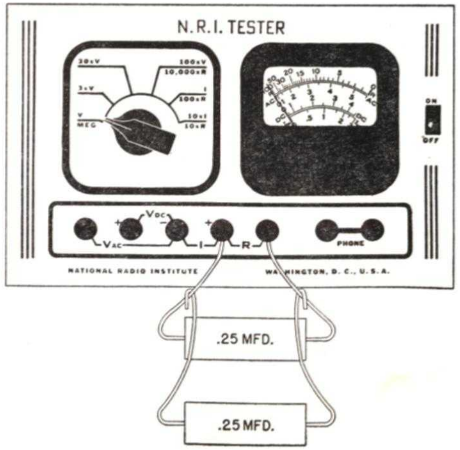


FIG. 14. Method of charging a .5-mfd. capacity for Step 1 of Experiment 25. (Two .25-mfd. condensers in parallel have a combined capacity of .5 mfd.)

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-

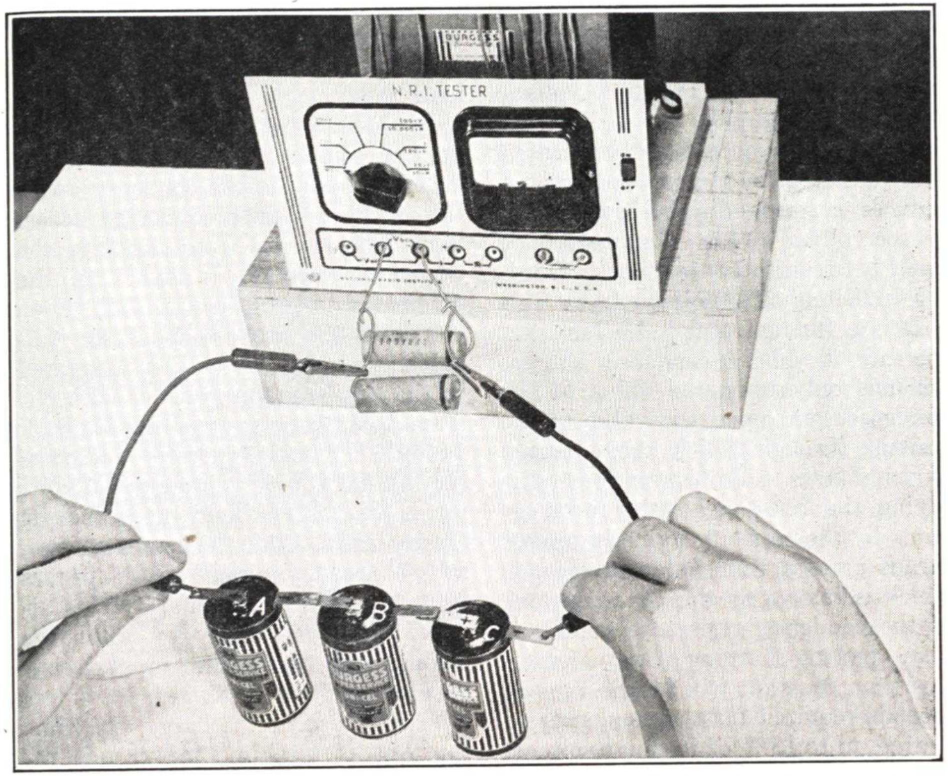


FIG. 15. Photographic illustration showing how apparatus is set up for Step 2 of Experiment 25.

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

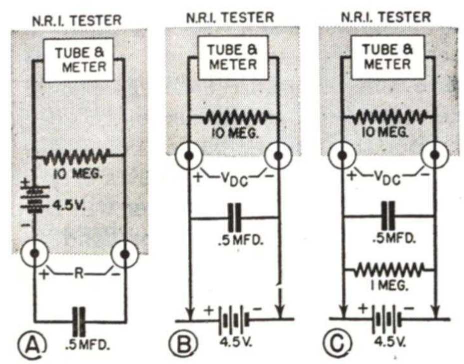


FIG 16. Schematic circuit diagrams for Experiment 25.

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	.7	.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= 100 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.

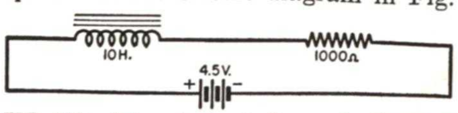


FIG. 17A. Schematic circuit diagram for Step 1 of Experiment 26.

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.

A 200-ohm resistor is used in place

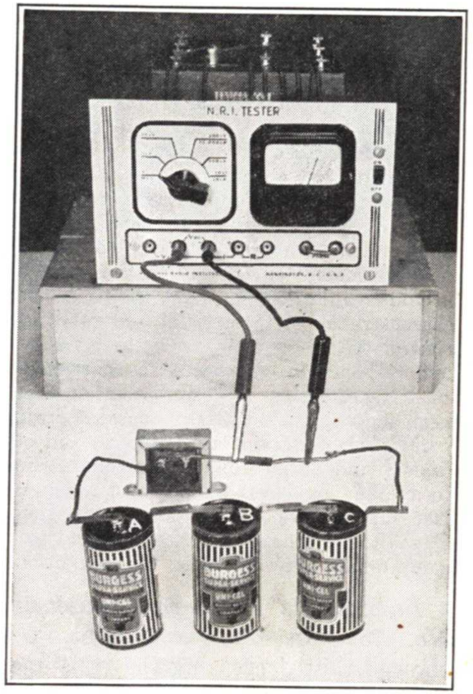


FIG. 17B. Method of measuring the voltage across the 1,000-ohm resistor in the coil-resistor circuit which you set up for Step 1 of Experiment 26.

of the coil, because the coil has a d.c. resistance of about 200 ohms.

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.

Before making a resistance measurement with the N.R.I. Tester, it is

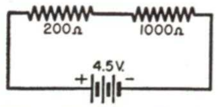


FIG. 18. Schematic circuit diagram for Step 2 of Experiment 26.

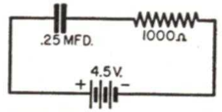


FIG. 19. Schematic circuit diagram for Step 3 of Experiment 26.

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

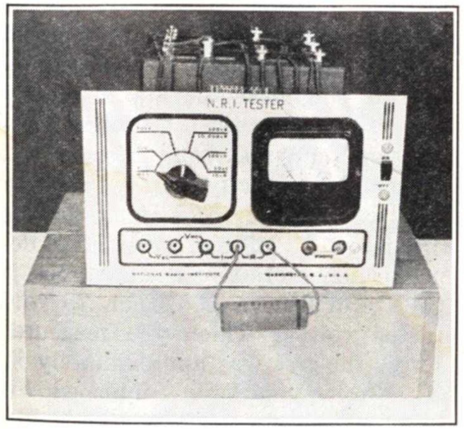


FIG. 20. Method of measuring the resistance of a .25-mfd. condenser with the N.R.I. Tester. Resistances up to 100 megohms can be measured with the N.R.I. Tester in this manner when the selector switch is set at *MEG.*

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.

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

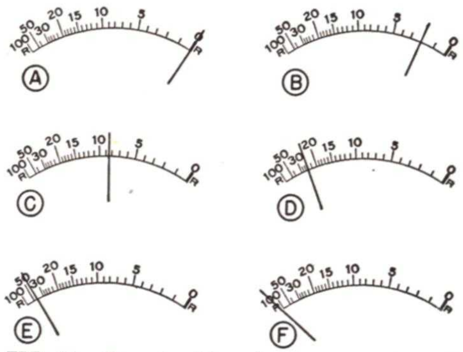


FIG. 21. Examples illustrating how to read the *R* scale on the meter of your N.R.I. Tester. The readings are as follows: *A*—0; *B*—2.0; *C*—8.5; *D*—24; *E*—40; *F*—INFINITY.

ohmmeter, and its indications are read directly in megohms on the *R* scale at the top of the meter.

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.

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

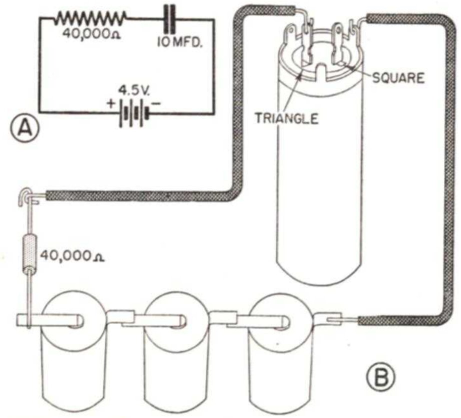


FIG. 22. Schematic (*A*) and semi-pictorial (*B*) circuit diagrams for Step 5 of Experiment 26.

an electrolytic condenser when it is improperly connected.

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 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

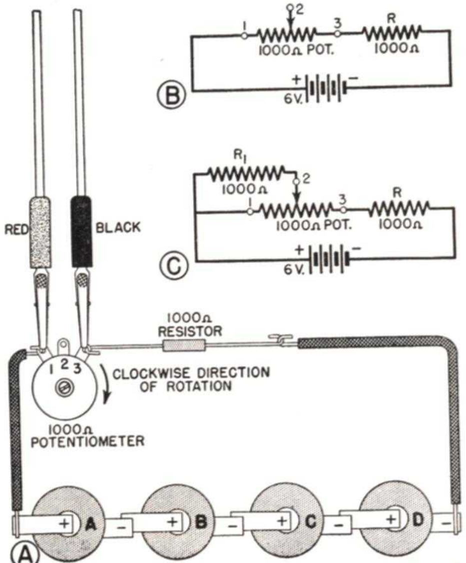


FIG. 23. Semi-pictorial (*A*) and schematic (*B* and *C*) circuit diagrams for Experiment 27.

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.

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.	3.2	2.9
	VOLTAGE ACROSS 1000Ω RES. R	3.0	3.1
2	VOLTAGE AT 0 ROTATION	0	0
	VOLTAGE AT ¼ ROTATION	.6	.6
	VOLTAGE AT ½ ROTATION	1.4	1.4
	VOLTAGE AT ¾ ROTATION	2.1	2.1
	VOLTAGE AT FULL ROTATION	3.3	2.9
4	VOLTAGE ACROSS 1000Ω POT.		2.1
	VOLTAGE ACROSS 1000Ω RES. R		3.9
	VOLTAGE AT 0 ROTATION		0
	VOLTAGE AT ¼ ROTATION		.5
	VOLTAGE AT ½ ROTATION		1.1
	VOLTAGE AT ¾ ROTATION		1.4
	VOLTAGE AT FULL ROTATION		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 potentiometer 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.

* The method of calculating this combined resistance of two resistors in parallel is given here for students who are interested:

$$R = \frac{R_1 \times R_2}{R_1 + R_2} \qquad R = \frac{1{,}000 \times 500}{1{,}000 + 500}$$

$$R = \frac{500{,}000}{1{,}500} \qquad R = 333 \text{ ohms}$$

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*).

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

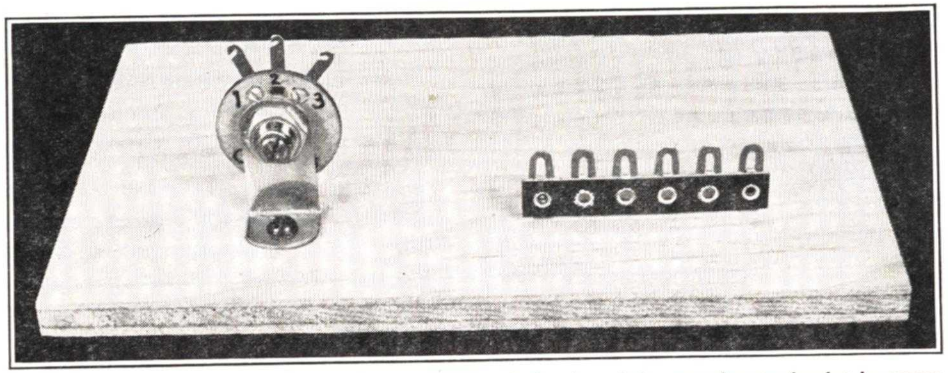


FIG. 24. For Step 1 of Experiment 28, mount the terminal strip and the potentiometer bracket in approximately the positions shown here, on a wooden base-board approximately 5" wide, 7" long and ½" thick.

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.

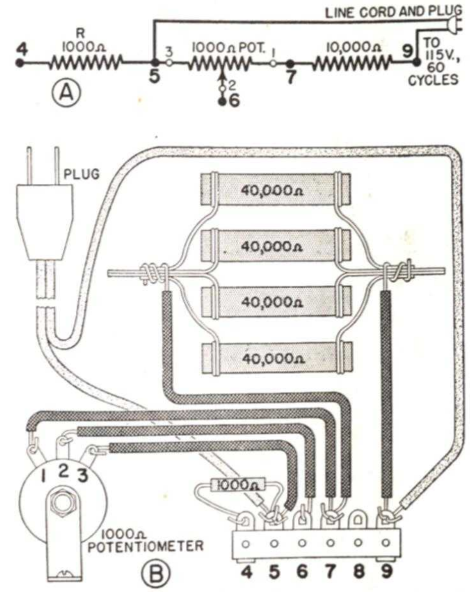


FIG. 25. Schematic (*A*) and semi-pictorial (*B*) circuit diagrams for the a.c. power supply source which you set up in Step 1 of Experiment 28.

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

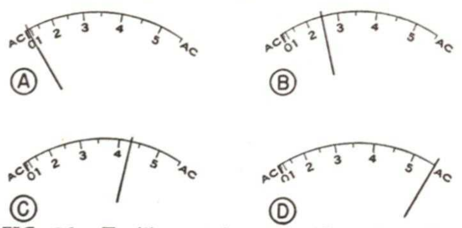


FIG. 26. To illustrate how the *AC* scale on the meter of the N.R.I. Tester is read, readings corresponding to four different positions of the pointer are given in these examples. The readings are as follows: *A*—.5V; *B*—2.5V; *C*—4.3V; *D*—5.5V.

one hand, and no part of your body is grounded, there will be no danger of shock.

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 black 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	112	120
	VOLTAGE BETWEEN 5 AND GROUND	0	0
	VOLTAGE BETWEEN TERMINALS 5 AND 9	112	120
	VOLTAGE BETWEEN TERMINALS 7 AND 9	90	108
	VOLTAGE BETWEEN TERMINALS 5 AND 7	9	12
5	VOLTAGE ACROSS 1000Ω R_1		2.4
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)		2.5
6	VOLTAGE ACROSS .5 MFD. C		4.9
	VOLTAGE ACROSS R (SAME AS CURRENT THRU C IN MA.)		.9
7	VOLTAGE ACROSS 10 MFD. C		1.9
	VOLTAGE ACROSS R (SAME AS CURRENT THRU C IN MA.)		4.6
8	VOLTAGE ACROSS 10 HENRY L		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

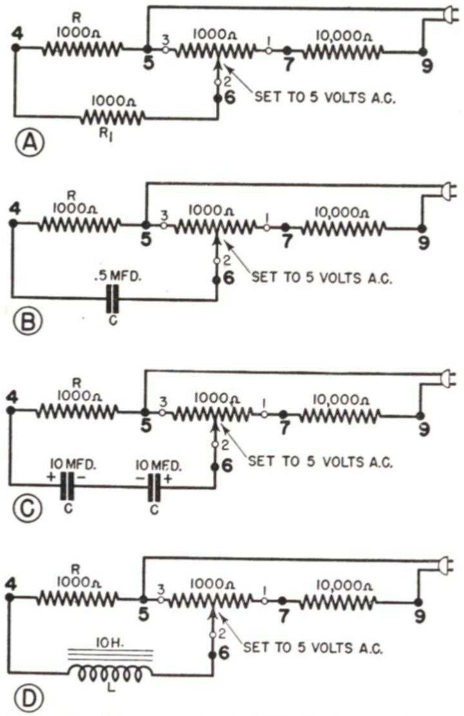


FIG. 27. Schematic circuit diagrams for the circuits which you set up in Steps 5, 6, 7 and 8 in Experiment 28 to determine how resistors, coils and condensers behave in 60-cycle a.c. circuits.

enough to fuse the solder and give a temporary soldered lap joint at each terminal.

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.

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.

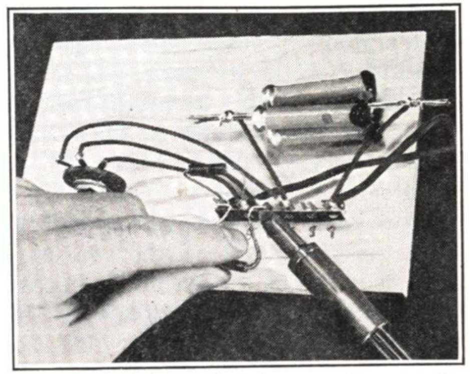


FIG. 28. This illustration shows you how to make a temporary soldered lap joint for the purpose of connecting a radio part temporarily between two terminals. This technique allows you to hold the part with one hand (instead of holding the solder in that hand), and gives a joint which can easily be disconnected.

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.

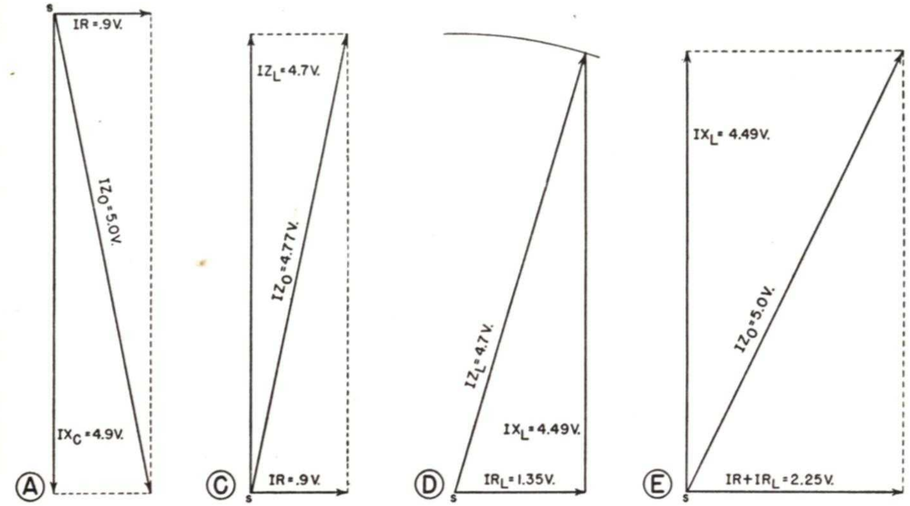
Let us compare the relative current-limiting actions of the .5-mfd. and 10-mfd. condensers in this a.c. circuit. We will use the N. R. I. values here for comparison, but you can do the same thing with those values you measured.

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



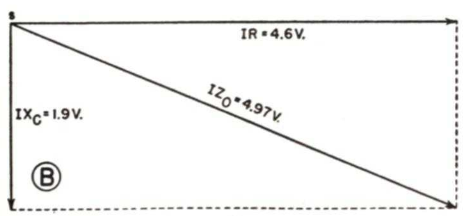


FIG. 29. These vector diagrams, based upon voltage values measured in the N.R.I. laboratory for the various steps of Experiment 28, prove definitely that Kirchhoff's Voltage Law holds true for a.c. circuits. One volt corresponds to ½-inch of vector length on these diagrams.

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.

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_L 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_0, 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.

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		4.0
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)		.3
2	VOLTAGE ACROSS .25 MFD. C		5.4
	VOLTAGE ACROSS 10 HENRY L		2.5
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)		1.0
3	VOLTAGE ACROSS .5 MFD. C		8.1
	VOLTAGE ACROSS 10 HENRY L		7.5
	VOLTAGE ACROSS R (SAME AS CURRENT IN MA.)		1.4
	VOLTAGE ACROSS .55 MFD. C		7.8
4	VOLTAGE ACROSS .5 MFD. C		11.4
	VOLTAGE ACROSS 10 HENRY L		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

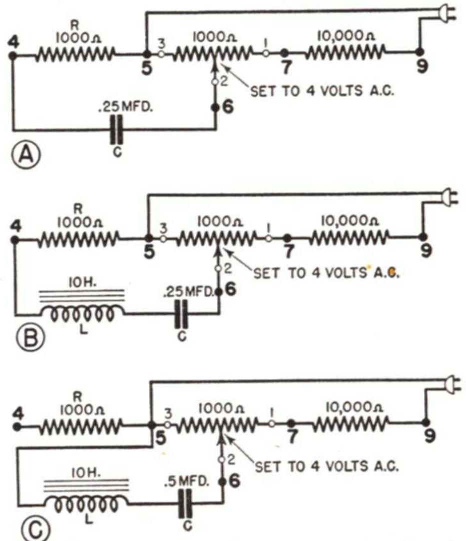


FIG. 30. Schematic circuit diagrams for Experiment 29.

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.

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

*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.

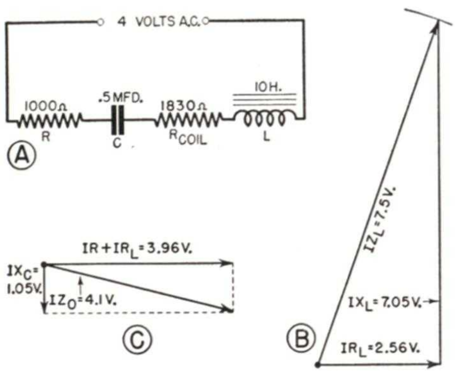


FIG. 31. Equivalent simplified circuit diagram corresponding to Fig. *30B*, and vector diagrams which prove that Kirchhoff's Voltage Law for a.c. circuits holds true in this particular circuit when tested out with the values obtained in the N.R.I. laboratory. One volt on these diagrams corresponds to 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.

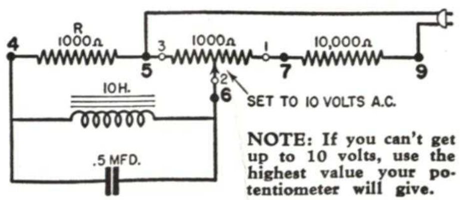


FIG. 32. Schematic circuit diagram for Step 2 of Experiment 30.

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		1.7
2	CURRENT THRU R,L AND C		.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.