NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

NRI

Radio-Trician
(Trade Mark Registered U. S. Patent Office.)

LESSON TEXT No. 2

(3rd Edition)

PRINCIPLES OF ELECTRIC CIRCUITS USED IN RADIO RECEIVERS

Originators of Radio Home Study Courses
··· Established 1914 ···
Washington, D. C.

"It was in making education not only common to all, but in some sense compulsory on all, that the destiny of the free republics of America was practically settled."—*James Russell Lowell.*

THE THREE S's OF SUCCESS

A Personal Message from J. E. Smith

"Systematic-Scientific-Study" is a motto you'll do well to remember. System is the principle of success. You can never hope to reach the greatest success of which you're capable if you are sloven in your habits of work. Therefore, in your study of this course, make up your mind to this one thing: you must be systematic. The three S's of SUCCESS are Systematic-Scientific-Study.

System is the first principle of science; science is the first principle of study, and study is the first principle of success.

There are two classes of students in the world, the systematic and the haphazard. Here are two students, Mr. S., who is systematic, Mr. H., who is haphazard and "hit-or-miss." Mr. S. begins by making a careful estimate of the time he has to spend and of the time required to do the work. He calculates that it will take him so many weeks to do the work by putting in so many hours a day. Mr. H. begins by plunging in headlong without stopping to estimate the time it will take or the energy required, trusting to luck that he will come out all right in the end. Mr. S. keeps a detailed and accurate record of his progress; Mr. H. keeps no record of any sort. Mr. S. has a certain time set aside for study and goes to his work when the time comes. Mr. H. works when "the spirit moves him." Mr. S. masters his work as he goes; Mr. H. skips the hard parts and hopes by good fortune to master them some day. But "some day" never comes. Mr. S. succeeds; Mr. H. fails. Will you be Mr. H. or Mr. S.?

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Radio-Trician's
(Trade Mark Registered U. S. Patent Office.)

Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

PRINCIPLES OF ELECTRIC CIRCUITS USED IN RADIO RECEIVERS

In the first lesson of this practical Radio course, we obtained a *bird's-eye view* of what Radio is, what it is supposed to accomplish, and in what manner these things are accomplished. In this, the second lesson of the course, we shall continue to follow out this "bird's-eye view," but in doing so we will gradually drift into the details of *Radio, electricity* and *magnetism*.

We know that electric currents flow along wires, or in fact in all materials. But in some materials the current finds great difficulty in flowing. For instance, the current flowing in the door-bell circuit can easily flow along the wire, and the metallic parts of the push-button. But it will be expected that the wiring, and the bell and the push-button must be mounted on some thing; the door-bell is screwed onto the wall, the batteries are set upon a wooden shelf, etc. It is evident that the electricity must be confined to our particular door-bell circuit. It is also evident that in order to so confine it, we must mount the various instruments on materials that will not easily conduct the electricity away from the circuit.

CONDUCTORS AND INSULATORS

Experience has taught investigators in their study of electrical phenomena that materials may be divided into classes; one class of materials conducts electricity very easily; another class of materials conducts electricity only with difficulty. There is no sharp dividing line between the two classes of materials. For instance, silver conducts electricity slightly better than copper, copper better than aluminum; aluminum better than iron, iron much better than German-silver.

For convenience, it has been found that three groups of materials will cover all practical purposes:

(a) Materials which conduct electricity very easily, called *conductors.*

(b) Materials which conduct electricity with slight difficulty, called *resistors*.

(c) Materials which conduct electricity only with great difficulty, called *insulators*.

Under these three groups fall the following materials:

(a) Conductors: Silver, copper, platinum, mercury, nickel, iron; in fact, nearly all metals.

(b) Resistors: German-silver, carbon, various metallic alloys, as manganin, constantan, etc.

(c) Insulators: Porcelain, bakelite, dry wood, glass, silk, cotton, rubber; in fact, most non-metallic materials.

RESISTANCE IN CIRCUITS

Let us first follow out the line of reasoning that a plumber employs after a house is built and all the water-spigots are installed. The plumber has to connect the water supply pipe between the house and the water main running under the street, which comes from the city pumping-station. The first thing the plumber does, is to count the number of water outlets in the house, and consider how much water is likely to be demanded from the main at any time. If this amount of water is great he then chooses a rather large pipe to connect the water main and the house. If the amount of water is small he need use only a small pipe. In other words, he chooses the size of pipe that will best accommodate the demand for the water. So it is with electricity. The larger the wire chosen to carry the electric current, the easier it will carry it. If we use a very fine wire, it will be able to carry only a small amount of electrical current.

In installing the water supply pipe, the plumber also has to consider the distance between the house and the water main in the street. For the greater this distance, the greater will be the amount of friction encountered by the water in flowing through the pipe, and this friction will make the flow of water slightly more difficult. It is, therefore, necessary, in order to counteract this dropping of the *water-pressure,* to use a larger pipe than he would if the distance were short.

The same thing holds true in electrical circuits, and we can formulate the laws of current flow in a wire in the following manner:

(a) The larger the wire the less the *resistance* it offers to the flow of current.

(b) The shorter the wire the less the *resistance* it offers to the flow of current.

(c) The less the *specific resistance* the less the resistance the wire offers to the flow of electric current.

The student will note that we have used two new terms in the preceding paragraph, viz., *resistance* and *specific resistance*. The word resistance is a general term, signifying the total amount of opposition the wire offers to the flow of current. The term "specific resistance" relates to the opposition a wire offers to the flow of current, regardless of the wire size and length, etc. For instance, if we have two wires of equal length and diameter, one wire having twice the *resistance* of

Testing the Circuits of a Radio Receiver.

the other, we say the *specific resistance* of the one is twice that of the other. In other words, the specific resistance of a conductor depends only upon the material of which it is made; the total resistance of the conductor depends not only on the material, but also on the length and diameter.

When we were talking about the plumber's problem of connecting water pipes to a house, we had occasion to use the word *pressure*. It is well known that when we have a high water-pressure in the water mains, there is a much greater chance of getting all the water we need into the house. Also when the pressure is high, the friction (or resistance) of the pipe to the flow of water is overcome, and a smaller pipe may be used to bring the same amount of water to the house.

Once again, similar things are true of the flow of electric current in wires. A *pressure* of some kind is required to make the electricity flow through the wire just as pressure is required to make the water flow through the water pipe. Water-pressure is measured in pounds, but electric pressure is measused in *volts*. The pressure is also called the "*potential*" in certain cases, which we shall learn about later on.

The amount of water flowing in a pipe is measured in *gallons* and the rate at which it flows in *gallons-per-minute*. In electrical circuits the *amount* of electricity flowing is measured in *coulombs;* the rate at which the electricity flows is measured in *coulombs-per-second*. The phrase "gallons-per-minute" has not been given any special name, but the phrase "coulombs-per-second" has been called "*amperes*." The "resistance" in an electrical circuit is measured in *ohms*.

Do not be alarmed at these strange names, if you have not heard them before; they are the names of great scientists who made important discoveries in electricity, and who have been honored by having their names used as the various units of electricity. Now let us compare the flow of water in a pipe with the flow of electricity in a wire, in tabular form:

Flow of Water in a Pipe		**Flow of Electricity in a Wire**
Pressure	Pounds	Volts
Opposition	Friction	Resistance
Amount	Gallons	Coulombs
Rate	Gallons-per-minute	Coulombs-per-second (amperes)

We now have a means of calculating what is going on in a simple electrical circuit energized by a battery and carrying an electric current. First let us see how we can calculate what is going on in the water pipe, for that is more familiar to us. Suppose, that in a certain pipe there is water flowing at the rate of 10 gallons per minute. It is clear that in 10 minutes 10x10 or 100 gallons of water will have flowed through the pipe.

In the electric circuit, suppose that electricity is flowing at the rate of 10 coulombs-per-second. Then in 10 seconds 10x10 or 100 coulombs of electricity will have flowed through the wire. Or, if we use the term "ampere" instead of "coulombs-per-second," the same holds true.

OHM'S LAW

There is a simple relation which holds true in simple electric circuits, however, which does not hold true for water systems, so we must drop our water pipe analogy for the present. This simple relation deals with the rate of current flow, the pressure and the resistance. Suppose that our door-bell circuit is connected to a battery which has a pressure of 15 volts. Suppose also that the circuit has a resistance of 5 ohms. Current will then flow through the circuit at the rate of 15 divided by 5 or 3 coulombs-per-second, that is at the rate of 3 ampere. In other words, if we divide the pressure by the resistance we obtain the current. There are *three ways* in which this simple relation can be expressed, so that when we know any *two* of the three quantities, *current, pressure* or *resistance,* we can always find the other quantity. These relations are:

$$\text{Current (in Coulombs-Per-Second or Amperes)} = \frac{\text{Pressure (in volts)}}{\text{Resistance (in ohms)}} \quad (1)$$

$$\text{Pressure (in volts)} = \text{Amperes} \times \text{Resistance} \quad (2)$$

$$\text{Resistance (in ohms)} = \frac{\text{Pressure (in volts)}}{\text{Current (in amperes)}} \quad (3)$$

These relations are quite simple. We can see how simple they are if we abbreviate the ideas. For instance, instead of writing it all out, let us use the letter I for the current in amperes, the letter V (E is sometimes used) for the pressure in volts, and the letter R for the resistance in ohms. Then these relations look as follows:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \quad \text{or} \quad I = \frac{V}{R} \quad (4)$$

$$\text{Volts} = \text{Amperes} \times \text{Ohms} \quad \text{or} \quad V = I \times R \quad (5)$$

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}} \quad \text{or} \quad R = \frac{V}{I} \quad (6)$$

Now let us see how things like this apply to the Radio receiver. As you know, there are a number of electron tubes in the set which are very much like ordinary incandescent lamps in certain respects, having a filament something like an incandescent lamp, which is heated by the electric current. This filament is heated by an electric current supplied by a storage battery, as shown in Fig. 1.

There is also an instrument included in the circuit, which is called a *rheostat.* This is a wire made of high resistance material wound upon an insulating strip, perhaps of fibre, and there is a metallic arm which can be revolved by a handle, so that this arm can make contact with the various turns of wire as it slides over them. The purpose of this rheostat is to introduce considerable *resistance* into the electric circuit. The arm is made movable so that we can adjust this resistance to the proper value. The electron tube has been so designed that it will work best when a certain amount of current is flowing through it. If we use more than this amount the "life" of the tube will be shortened, and if we use less than this amount the tube will not operate well. So we adjust the amount of resistance in the circuit so that the proper amount of current is permitted to flow through the filament circuit of the tube.

The electron tube used in many battery operated receivers is known as the UX-201-A. This tube has been so designed that it operates best when a pressure of 5 volts is put upon it, and a current of 0.25 (which is the decimal expression for ¼) of an ampere is flowing through the filament. Now. applying the things that we have learned before, the resistance of the filament in the tube is obtained as follows:

$$R = \frac{V}{I} \quad \text{or} \quad R = \frac{5}{0.25} = 20 \text{ ohms} \qquad (7)$$

The resistance of the filament is therefore 20 ohms.

The next problem is to find out how much resistance we must have in the rheostat, in order that 0.25 of an ampere of current shall flow through the circuit, when the pressure of the battery is 6 volts. Once again, in order to find the total amount of resistance required in the circuit, we have:

$$R = \frac{6}{0.25} = 24 \text{ ohms} \qquad (8)$$

This is the total resistance required in order that the 6 volt battery will send 0.25 of an ampere through the complete circuit. But the filament of the electron tube already furnishes 20 of the 24 ohms, so all the resistance we need in the rheostat is 4 ohms. We are therefore enabled to choose the proper rheostat immediately. The nearest size rheostat made commercially has a total of 6 ohms of resistance, and by moving the contact arm the resistance can be reduced to less than 1 ohm. By choosing this particular rheostat we can obtain the 4 ohms we need by moving the contact two-thirds the way around so that only two-thirds (or four-sixths) of the resistance is used.

The reason for this can be seen by referring to Fig. 1-A. which is like Fig. 1, excepting that the rheostat (R) has been stretched out straight. We have divided this rheostat into

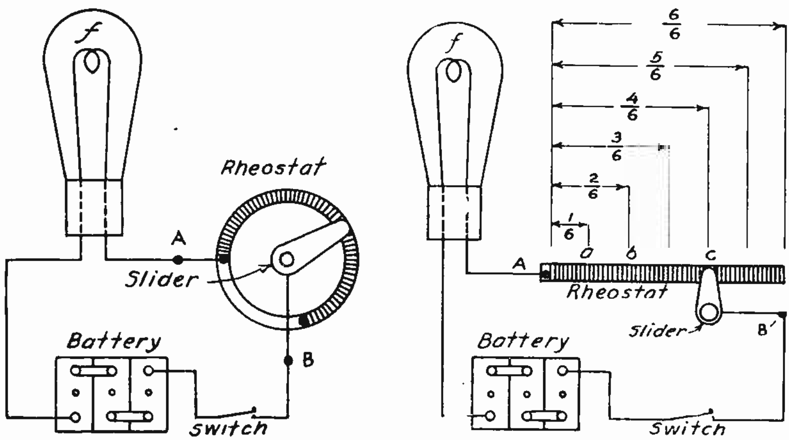

Fig. 1

Fig. 1-A

six equal parts, so that counting from the end A, where the slider starts, we can count off or introduce into the circuit as many of these parts as we wish by merely moving the slider to the right. Thus, if the slider is at a, we have one-sixth of the rheostat in the circuit, and since the total resistance of the rheostat is 6 ohms, this means we have 1/6 of 6 ohms or 1 ohm in the circuit. When we move the slider to b we have 2/6ths (which is the same as 1/3rd) of 6 ohms or 2 ohms, in the circuit. Every time we move the slider a sixth we introduce another ohm into the circuit. When the slider is at the point c, we have included in the circuit 4/6ths (or 2/3rds) of the total, and 4/6ths of 6 ohms gives 4 ohms, which is the resistance we need in series with the filament of the tube under consideration.

It makes no difference where we place the rheostat in the circuit, nor any of the other pieces of apparatus, in this case. We can connect them in the circuit in any order we please. The same current will flow in the circuit regardless of the order in which the apparatus is connected. This can be readily appreciated when you consider that when water is flowing through a pipe, whatever water goes into the pipe at one end must come out the other end. This is true of all electrical circuits in which there is only one path for the current to travel—what we will call later, a *series* circuit, in which there is a series of instruments, one behind the other. As far as the amount of current in the circuit is concerned, it makes no difference in a series circuit what the order of the apparatus happens to be.

It must be remembered that *all conductors* have *resistance*. The difference between conductors of various materials, with regard to their resistance, is the *amount* of resist-

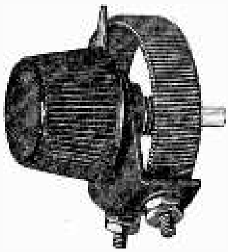

Fig. 2—Filament Variable Rheostat.

ance they have. Every part of the path through which the current flows, in Fig. 1, has resistance, even the battery which supplies the electrical energy. The liquid in the battery, called the *electrolyte*, has a small amount of resistance, perhaps a tenth of an ohm or less. This is so small that we generally neglect it in making rough calculations such as we have done heretofore. The copper wire itself, with which we make the connections from one instrument to another in the circuit, has a small amount of resistance. The amount of resistance in the wiring depends, as we have seen, on the diameter and the length of the wire.

Wire sizes have been arranged by the manufacturers of wire in an orderly manner, which we shall learn later on, but for the present, the wire Table No. I is given for the student's reference. In it are shown the *gauge numbers* by which the various sizes are known, instead of speaking of these sizes as so-many thousandths of an inch in diameter.

Thus we speak of a number 20 wire, which has a certain diameter, as shown in the table. The machinist speaks of drill sizes in a very similar manner, a number 20 drill, meaning a drill with a certain particular diameter. The various gauge systems are different, that is, the system of drill gauges is not the same as the wire gauge. There are also special gauges for special kinds of wire, as, for instance, the "steel wire gauge." In Radio, however, we are for the most part interested in the gauge which applies to copper wire only, so for

Copper Wire Table No. I

Size B. & S Gauge	Diam Bare wire in inches	Ohms per 1,000 ft.
16	.0508	4.009
17	.0453	5.055
18	.0403	6.374
19	.0359	8.038
20	.0320	10.14
21	.0285	12.78
22	.0253	16.12
23	.0226	20.32
24	.0201	25.63
25	.0179	32.31
26	.0159	40.75
27	.0142	51.38
28	.0126	64.79
29	.0113	81.70
30	.0100	103.0

this purpose we use a gauge system known as the Brown & Sharp system, named after a great tool manufacturing concern. It is commonly abbreviated "B & S." It is also known as the "American Wire Gauge" to distinguish it from the British gauge.

It is seen in the table that each wire size has a certain amount of resistance for each foot of wire. Thus No. 20 B & S gauge wire has a resistance of 10.14 ohms per 1,000 feet.

The rheostat has, as we have seen, a rather large amount of resistance, compared with the resistance of the battery and the connecting wires. It has intentionally been made to have this resistance. It consists of a wire wound around a form, and the contact arm, or slider, moves over the edges of the turns of wire so that it can make contact with each separate turn successively. This is done to make it possible to *vary* the amount of resistance included in the circuit. Figure 3 shows a portion of such a rheostat. The points A and B are the same as the points A and B in Fig. 1. When the contact arm is in the position C, the current has to flow through all the resistance wire from A to C and then to B. When the contact arm is in the position D, the current has to flow through only a portion of the resistance and then to B, making the resistance in the circuit less.

Table No. II

Material	Relative Resistance
Silver	0.925
Copper	1.000
Aluminum	1.587
Iron	9.
German-silver	17.3
Manganin	29.3
Constantan	32.
Nichrome	100.

The particular wire used may have many times the resistance per foot of copper wire. Suppose we have a number of wires of different materials, all having the same diameter and length. The resistance of the copper wire will be so many times the resistance of the silver wire; the iron wire will have so many times more resistance than the copper wire. Likewise, it is true with wires of other materials, such as we have mentioned in Table No. II. By referring to this table we can find out exactly how much more resistance a certain kind of wire has in comparison with copper. For instance, the relative resistance of German-silver is 17.3. This means that a piece of wire made of German-silver has 17.3 times the resistance of a piece of copper wire of the same length and diameter. Suppose we have a 1 foot length of German-silver wire, size 20 B & S gauge, and we wish to know its resistance. Look in the table of copper wires.

The resistance of 1,000 feet of No. 20 copper wire is shown to be 10.14 ohms. This means that one foot of the wire would have a resistance 1/1,000th as great, or 10.14/1,000th or 0.01014 ohm, or roughly, one-hundredth of an ohm (0.01 ohm). Now, Table II gives, as the relative resistance of German-silver wire, 17.3. This means that German-silver wire is 17.3 times more resistant to the flow of current than copper wire. So the resistance of our one foot of German-silver wire will be 17.3 x 0.01 or 0.173 ohm per foot.

We can make this quite plain by doing our problem in the form of a table, thus:

	Ohm.
Resistance of 1,000 feet of No. 20 copper wire........	10.14
Resistance of 1 foot of No. 20 copper wire, 10.14/1,000	0.01014
Relative resistance of German-silver................	17.3
Resistance of 1 foot of No. 20 German-silver wire 17.3 x 0.01014	0.173

We now come to the filament of the electron tube. We have seen in the case of the 201-A tube which we studied before, that its resistance is 20 ohms. This high resistance is obtained in such a short piece of wire, by making the diameter of the wire very small. The filament is usually made of

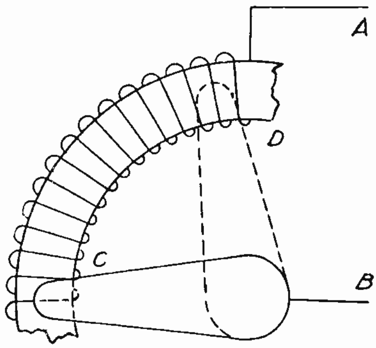

Fig. 3—Portion of a Rheostat Illustrating How the Resistance is Varied.

tungsten, which has a higher relative resistance than copper wire. The higher relative resistance, combined with the small diameter of the wire, enables us to get a lot of resistance in a wire as short as the filament of one of these tubes, which may only be about two inches or less in length.

We have now completely covered the circuit of Fig. 1 with respect to the distribution of resistance in it. But we have more to learn about what resistance does in an electrical circuit. We have learned that resistance in a circuit offers opposition to the flow of the electric current. To what does this opposition lead?

Let us, for the sake of clearness, consider what opposition may do in other fields. Think again of the water pipe. The friction of the pipe against the water flowing in it causes a loss in pressure. This loss of pressure amounts to the same thing as a loss of some of the energy that is in the water, and the energy so lost is converted into heat. Of course this heat may not be noticeable, for the water continually coming in takes up this heat and carries it off, thus keeping the pipe cool.

Now let us think of another comparison. Suppose we take a file, and rub a piece of brass on it. There is a great friction between the file and the piece of brass, and if we rub hard and long enough, the piece of brass may become so hot that we cannot hold it. This is a very good example of how mechanical energy can be converted into heat energy. We have the same thing happen when sparks fly off a grindstone, or when a car-wheel slides on the car-track.

In a very similar manner, electrical energy in a circuit can be converted into heat energy. The resistance in the circuit, offering opposition to the flow of current, causes some of the energy to be converted into heat. The amount of heat so *generated* depends upon the *amount of the resistance* and

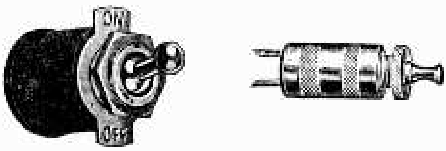

Fig. 4.—Types of Filament Switches.

the *amount of current* flowing through it. When the current is small the amount of heat so generated is small; when the resistance is small the heat generated likewise is small. When it is easy for this heat to flow away into other bodies or be radiated into space, we do not generally notice the rise in temperature of the wire carrying the current.

On the other hand, when a great amount of heat is confined to a small space it is often easy to feel the heat. For instance, a great deal of resistance is confined to a small amount of space in the rheostat. The wire is wound on material which does not conduct heat away very easily. Consequently, if the rheostat is carrying a fair amount of current we can feel the heat by touching our finger to the resistance wire in the rheostat.

As another illustration of this heating effect, take the case of the filament. This is heated to such a degree that the filament becomes luminous. It acts just the same as an incandescent lamp, although to a smaller degree. The heat finds it extremely difficult to escape or flow away from the filament, as the latter is enclosed in a vacuum. This explains why the wire gets red hot and gives off light.

We will find, as we study further, that this heating effect of electrical currents is a very serious thing. It does not worry us much in electric heaters, where we want the heat, but in most cases we do not want it since it means that some of our electrical energy, which we want to use for other purposes,

Fig. 5.—Sketch Illustrating Action of Filament Switch.

is being lost in the form of heat. As we have said before, we must be very careful where we allow resistance to enter into the electrical circuit. This is especially true of the electrical circuits which we have in Radio receivers. There are only a few places in Radio receivers where we actually *want* resistance, such as in the filament or in a rheostat, etc. But when we have resistance in other places where we do not want it, there is always a loss of electrical energy, due

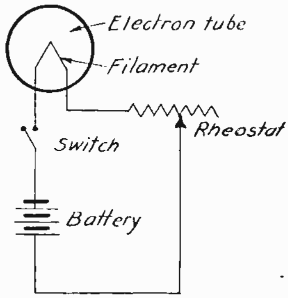

Fig. 6—Filament Circuit of a Vacuum Tube.

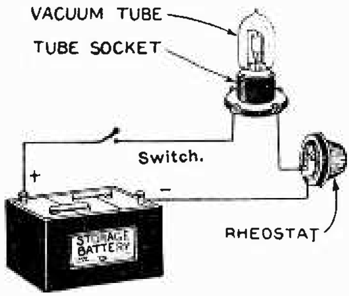

Fig. 6-A—Pictorial View of Apparatus.

to the generation of heat in the wires and conductors. This heat is generally extremely small, so that we cannot notice that it is being generated. But we can notice this loss in other ways. The energy which is in the Radio waves, which the receiver detects and amplifies, is extremely small, and we must be careful not to lose any more of it than we can possibly help. If we lose any appreciable amount of it, we will find that our receiver is not very sensitive. If we have a considerable amount of resistance in the circuits of the receiver, we may be able to receive signals only at a distance of, say, 500 miles, instead of 1,000 miles or more. Of course, the presence of resistance in Radio circuits has more effect than this, but the loss of *sensitivity*, as it is called, is perhaps the most serious effect of resistance.

Figure 1 shows the filament connections of one of the electron tubes which we find in a Radio receiver. The only thing we have not included is a *switch*, which is a device to turn the current off and on as we desire. A photograph of a switch is shown in Fig. 4. This switch may be connected at any point in the simple circuit such as we have in Fig. 1, but it is generally placed in the circuit near the battery. Figures 6 and 6-A shows this arrangement, they are the same as Fig. 1,

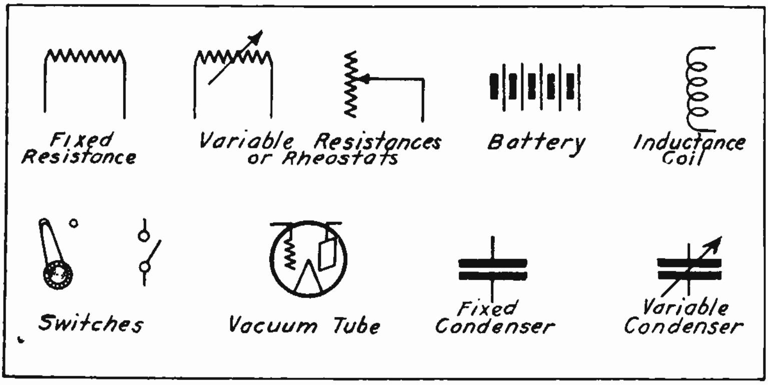

Fig. 7—A Few Radio Symbols.

excepting for the switch. The two diagrams look different because in Fig. 6 we have used a shorthand method of illustrating the various parts of the circuit. The student must become accustomed to using these short-cut ways of representing electrical circuits. They are used continually in Radio engineering.

For instance, an ordinary resistance, which cannot be varied or adjusted, is represented by a kinky line, such as we see in Fig. 7. A resistance which we can adjust is shown in the same manner, excepting that now we cross the kinky line with an arrow, or else indicate one of the connections to it by means of a small arrow head. A *variable resistance* is called a *rheostat*. A battery is represented by a series of long, thin lines in between short thick lines. These represent *cells* of a battery. This is what we have shown in Fig. 7. However, the correct number of cells is not always shown in drawings and diagrams. A switch can be represented in a number of ways, all meaning the same thing, however, since all switches are used for making and breaking electrical circuits at will. Two of these ways of representing switches are shown in Fig. 7 along with other symbols.

PARALLEL CIRCUITS

Now in Radio receivers we generally have several tubes, often as many as six or more. All of the tubes are lighted by the same source of electric current, whether it be from a battery or from the house lighting system, so we must find out how this is done. Let us go back to our old water pipe again, and we shall quickly learn all about it. At the same time let us look at Fig. 8. Here we have a large reservoir which holds a lot of water. We have a number of small tanks, which

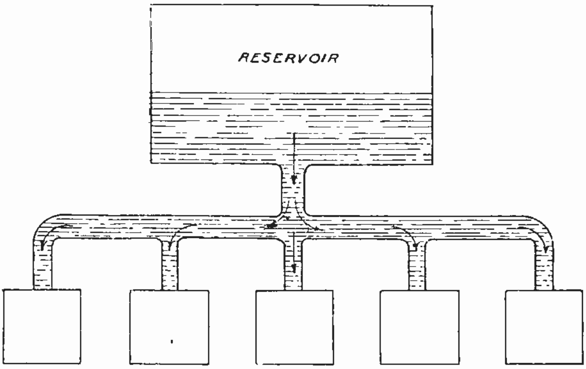

Fig. 8.

we wish to fill with water from the reservoir. We can do this by using an arrangement of piping as we have shown. This arrangement is called a *manifold;* many of you who have worked around automobiles will understand immediately what we mean. The water flows into the piping from the reservoir, as indicated by the arrow at the bottom of the reservoir, and then it divides into the several other channels through which it finally flows into the small tanks at the bottom.

The manner of connecting several electron tubes together so that they can all be lighted by the same battery is very similar to Figs. 8 and 10. The arrangement is shown in Fig. 9, where we have, for example, connected together four tubes. When the switch is closed, the current flows out of the battery and through the rheostat. It then reaches the point "A" where it divides into the various branches in much the same manner as the water divided among the various outlets of the manifold in Fig. 8. Each tube therefore has enough current passing through it to heat it. The four different currents passing through the four tubes unite at the point "B" of Fig. 9, and then continue on in the circuit, going through the switch and back to the battery. Of course, there is not a very close similarity between this electrical circuit and the water system of Fig. 8, but we can get a better idea of this by studying Fig. 10. Here we have a reservoir, but this time it is being emptied by means of the pump. The water divides through the manifold at "A" and then passes through the four small tanks marked "T". These are supposed to represent the four electron tubes. The currents flow of water through the four tanks then unite again at "B" and pass back to the reservoir.

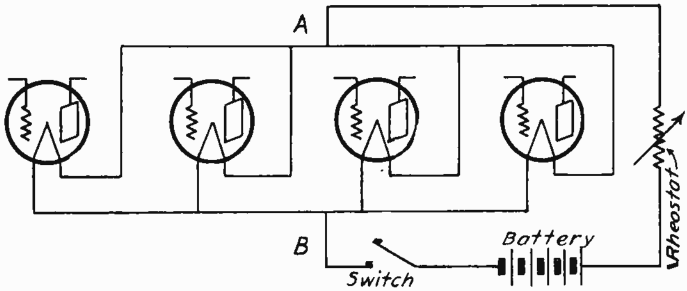

Fig. 9—Four Vacuum Tube Filament Circuits Connected in Parallel

The pressure of the pump in Fig. 10 represents the voltage of the storage battery. The flow of water represents the electric current. We have now learned, in a simple manner, how the tubes of the Radio receiver are lighted and how they are "wired" together so that they may all be lighted by the same battery. We can also see, in Fig. 9, how the brilliancy of all the tubes so connected can be controlled by means of one rheostat. But we shall now learn why this rheostat cannot be the same one which we were talking about before when we learned how to connect up a single tube circuit.

A little earlier in this lesson we learned that when we wish to light a UX-201A tube by means of a six volt supply, we had to add 4 ohms to the circuit in order to limit the current through the tube to 0.25 ampere.

But that was for a *single* tube. Now we have four tubes connected together. The method of connecting them is called a "*parallel*" connection, because all the currents through the tubes come from the same source. Now keep this in mind, and look at Fig. 10 again. Suppose instead of four small tanks there is only one tank for the water to pass through on its journey from A to B. It is clear that the water could not pass as rapidly. Suppose we have two small tanks for the water to pass through. There are then twice as many outlets for the water, and consequently the water can get from A to B with half the difficulty. Then as we add another and then another small tank, until we have four, it becomes easier and easier for the water to flow through.

The same is true with the circuit of the tubes, shown in Fig. 9. Just as the water flows in parallel paths from A to B in Fig. 10, through the different small tanks, so the electric current in Fig. 9 passes in parallel paths from A to B. Since

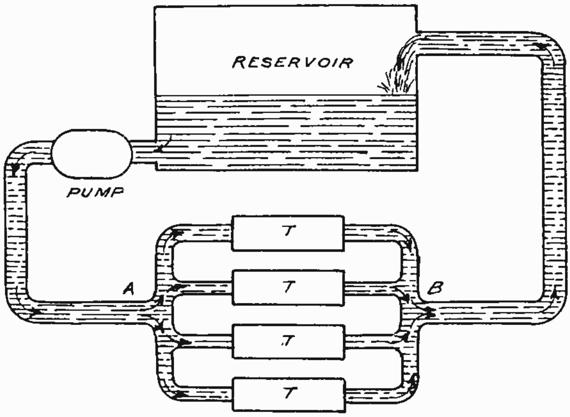

Fig. 10—Illustration Showing a Reservoir Pump and for Tanks Connected in Parallel

there are four of these paths in parallel, it is one-fourth as difficult for the current to flow through. Consequently the resistance between the points A and B of Fig. 9 is one-fourth the resistance of a single tube. Such is the case; when we have a number of parallel paths through which a current may flow, and the resistance of all the paths is the same, the resistance of all of them combined is the resistance of one of them divided by the number of paths.

For instance, we have seen that the resistance of *one* UX-201A tube is 20 ohms. If we have four of them connected in parallel, the *joint* or *combined* resistance is then 20 divided by 4, or 5 ohms.

Now, since it is one-fourth as difficult for the current to get through from A to B naturally four times as much current can flow. In other words, if each tube can take a current of ¼ of an ampere, four tubes in parallel can take 4 times this amount or 1 ampere.

Now we have a six volt battery and we wish to have a total current of 1 ampere flow from it. Using the law we learned before, that is: $R = V \div I$ we find that the resistance we have in the circuit is $R = 6 \div 1$ or 6 ohms, instead of the 24 ohms which we needed when we used only a single tube. Now the four tubes in parallel already furnish 5 ohms, so that now we only need an additional resistance of 1 ohm to be furnished by the rheostat. A six ohm rheostat, however, is the usual commercial size, so that we must use it, and for best operation we should set it about one-sixth of the way around, as can be readily understood by referring to Fig. 1-A. By doing this we shall be certain that the tubes are each carrying a current of ¼ ampere, giving a total current for the four tubes of 1 ampere.

It is not necessary to be able at this early stage of the course, to make such calculations, but it is good to understand how the different things which we find in electrical circuits affect the current and voltage of these circuits.

The student must also become familiar with the names of the various things, and obtain some idea of how great a resistance is, say 10 ohms; perhaps, when you were starting to learn about resistance, when you read that a certain electrical circuit had 20 ohms of resistance in it you did not know what to think. But when you learn that an electron tube, like the UX-201-A has 20 ohms of resistance in it, you begin to understand what an ohm means. You can further appreciate what it means when you think of some of the other good and bad conductors of electricity. For instance, the resistance of a piece of wood, which generally is a very poor conductor when dry, may be twenty or thirty *million* ohms. When damp it may be two or three million ohms. A piece of porcelain may have a resistance of fifty million ohms or more, in fact, it may be so high that we cannot measure it. A piece of No. 20 copper wire has a resistance of only one-hundredth of an ohm to the foot; a piece of No. 20 german-silver wire a foot long has a resistance of about two-tenths of an ohm. So you see that there is an enormous range in the resistance of electrical circuits, all the way from resistances which are too small up to those which are too high to measure. Keep these things in mind, and learn to "gauge" the size of resistance as we meet it in Radio circuits.

SERIES CIRCUITS

When we were learning a little while ago how several tubes are connected together in Radio circuits so that they could be operated by the same storage-battery, we said that they were connected in *parallel*. Now there is another way in which we connect electrical or Radio apparatus together, and we call this the "*series*" connection. Let us see what this is.

First, we all know the general meaning of the word "series"; it merely means a succession of things. That is, when we have a number of things, one following the other, we say we have a series. For instance, if we write 1, 2, 3, 4, 5, 6, 7, 8, 9, we have a series of numbers. So, if we connect a number of pieces of Radio or electrical apparatus together, one following the other, we have a *series* of pieces of apparatus,

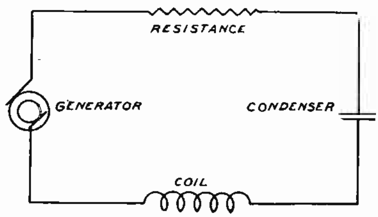

Fig. 11—Drawing Showing Series Connection to Several Pieces of Apparatus Using Symbols.

and this manner of connecting them is called the *series* connection.

In Fig. 11, for example, we have a number of pieces of apparatus connected in series. We have there an alternating current generator connected to a resistance, a condenser, and a coil, all in series. It will be noted that in this diagram we have used a number of symbols, such as we spoke of before. You learned before about the shorthand way in which we pictured a resistance, or a rheostat. In this diagram we also show how we picture a condenser, a coil, and an alternating current generator, in the shorthand method. There are reasons for these shorthand symbols. A condenser consists of two or more metal plates placed near to each other. Hence we represent it by drawing two short lines near each other. A coil consists of a lot of wire wound around a tube of insulating material. Hence we picture it somewhat as an artist would draw a coil of wire. An AC generator has two rings which revolve, and upon which slide pieces of copper or carbon, called the "brushes." Hence we show the two rings and a couple of lines sliding on them. Remember these symbols, for they are very important, being used all the time to draw the wiring diagram of Radio circuits. By means of these diagrams we can show in a few minutes how the most complicated Radio transmitters and receivers are built.

Now let us go back to our electron tube circuit, that is, the single tube circuit, which we saw in Fig. 6. We will reproduce it here in Fig. 12 for your convenience. It is a series circuit, for we have a battery, a rheostat, the filament of an electron tube and switch, all connected in series. One follows the other in succession as we go around the circuit. The current flowing out of the battery has to pass through first one piece of apparatus then the next, and so on, so that the same current must flow through all of them. To show how it all figures out, let us see how much resistance we have in that series circuit.

Suppose, as we saw before, the filament of the tube has a resistance of 20 ohms. Suppose also that we use a six ohm rheostat, and that we have the arm of the rheostat swung all the way around. In other words, all the resistance of the rheostat is in the circuit. In making the connections we had to use a certain amount of wire, depending upon how close together the various parts are located. Suppose the resistance of the wire is 0.1 of an ohm. The whole resistance in the circuit is then all these various resistances added together, including the resistance of the battery, which may be about ½ (0.5) of an ohm. This is:

$$0.5 + 6 + 20 + 0.1 = 26.6 \text{ ohms.}$$

Generally we neglect the resistance of the wiring and the resistance of the battery, because this is usually very small compared with the resistance of the rest of the circuit, so if we would omit these, we would simply say that the resistance of the circuit is 20 plus 6 or 26 ohms. This is accurate enough for most purposes. It is sufficient if the student knows that these other things have resistance.

This is the way in which series circuits work out, at least as far as the resistance is concerned. We have lots of series circuits in Radio receivers, as we shall see. Figure 11 shows a series arrangement that occurs in Radio circuits very often, in fact, in almost all the circuits of a Radio receiver we find a coil, condenser and resistance in series. Oftentimes this resistance is not there in the form of an actual rheostat, but is contained in the very wire of which the coil is made. It is clear that since we have to use wire to wind a coil, and since all kinds of wire have a certain amount of resistance, that the coil must have in it some resistance. When it does have resistance in it, we generally show it in wiring diagrams as being connected in series with the coil, for it is more easily understood then. We shall hear more of this later on.

Now, in order to understand how Radio circuits work, we must at this time begin to tackle the hardest problem of Radio receivers, and that is to understand how and why the condensers and coils work. In our first lesson we learned something about the meaning of *tuning;* we also came upon the idea of *resonance.* Remember the board on the bridge, which we *oscillated* up and down, keeping in time with the water

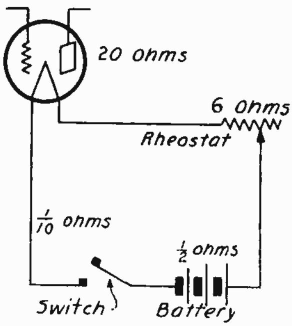

Fig. 12—Filament Circuit of a Vacuum Tube.

waves that flowed underneath. If we did not keep in time with them we would sometimes obstruct their flow. But by keeping in resonance, or keeping in time with them we permitted them to flow underneath unobstructed.

Remember how the violin string vibrated when *tuned* to another violin string which was near it? Remember also that the second violin string would not vibrate unless it were tuned exactly the same as the first one, in spite of the fact that the waves from the first string were striking against it? Well, we have the same thing in Radio. The Radio set at the receiving station, in your home, for instance, must be tuned to exactly the same frequency as the particular broadcasting station which you wish to receive. This tuning, as we have seen before in Lesson No. 1, is done by means of the condensers in the receiver. The tuning could as well be done by means of the coils, but this is not quite as easy, from the practical view-point. We will now begin to study what the coils and condenser do in Radio circuits, so that soon we will be able to understand the whole process that goes on in the set, will be well fitted to go out and work on them, and will have quite a broad knowledge of the idea of Radio so that the lessons which follow will be quite simple.

We will start our study with the condenser. An electrical condenser is a fairly simple piece of apparatus. It merely consists of a metal plate located rather close to another metal plate, and in between the plates we may have air, mica, or any good insulating material. The wires leading to this condenser are attached, or soldered to the metal plates. Such a condenser is shown in Fig. 13. This is the simplest form of condenser. In Radio circuits, as we have seen, a condenser is represented in a simple manner by drawing two short lines parallel to each other, and rather close together of equal length. This is shown in Fig. 11.

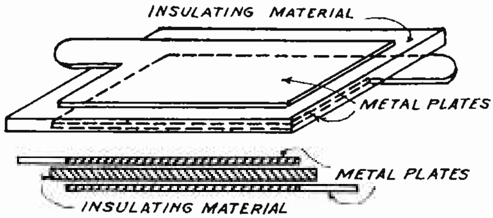

Fig. 13.—Constructional Details of a Simple Condenser.

Now suppose we have such a condenser connected to a battery, and a switch, as shown in Fig. 14. There is also connected in the circuit a *galvanometer,* a very sensitive instrument which indicates the presence of a current whenever one flows in the circuit. We will not worry now about how the galvanometer operates, for we will study measuring instruments later on. For the present remember that we have connected in the circuit a very sensitive instrument for detecting a flow of electric current.

At first, before we close the switch of the circuit in Fig. 14, there is no current flowing in the circuit. The battery has a voltage, or an electromotive force, but since the circuit is broken at the switch, no current can flow. Suppose now we close the switch. The voltage of the battery will cause a current to flow, which tries to find its way completely around the circuit. But when it comes to the condenser it finds a piece of insulating material in its path, through which it cannot easily flow. Consequently, after flowing out of the battery to the condenser, which takes only a thousandth or a millionth of a second perhaps, it stops flowing, and if we were to measure the voltage across the condenser—that is—the force which exists between the condenser plates which tries to make a current flow through the insulating material from one plate to the other—we should find it to be the same as the voltage of the battery.

In other words, by connecting the condenser to the battery, it has acquired a voltage, and this voltage is the same as the voltage of the battery.

Now, keeping all this in mind, let us look at it from another angle. We learned in Lesson No. 1 that all materials are composed of an enormous number of extremely small electrical particles called *electrons*. These electrons exist in the battery, in the wiring and in the condenser, as shown in Fig. 14. The chemical processes which are going on in the

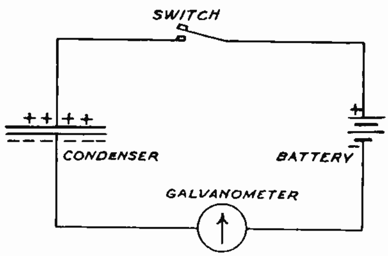

Fig. 14—Illustrating How a Battery Charges a Condenser.

battery cause a certain arrangement of the electrons within it which causes one terminal of the battery to *attract* other electrons to it, and the other terminal of the battery to *repel* other electrons from it. The terminal of the battery which repels the electrons is called the negative terminal or *pole* of the battery, and the terminal which attracts electrons is called the *positive* terminal or pole. In circuit diagrams, such as the one shown in Fig. 14, the positive pole of the battery is marked + (plus) and the negative pole is marked — (minus).

No energy is being taken from the battery until it is connected to an external or outside circuit such as the wiring and the condenser. The electrons are distributed through the wiring and the battery, and on the plates of the condenser, but are not moving in any particular direction. As soon as we close or complete the circuit by pressing the switch, the positive pole of the battery attracts the electrons which were on the plate of the condenser connected to it, and the negative pole of the battery repels the electrons near it onto the other plate of the condenser. There is, therefore, an increase in the number of electrons on the one plate (marked —) and a decrease in the number on the other plate (marked +). This was exactly the condition we had in the battery before the switch was closed, but now this condition has been permitted to advance along the wiring to the plates of the condenser.

The galvanometer will indicate this very small flow of current if it is able to act quickly enough, but as we have seen, all this takes place in an extremely small interval of time.

Now let us open the switch and see what happens. Doing this, we open the circuit; we may just as well remove the battery from the circuit, for this amounts to the same thing. But we have not as yet touched the plates of the condenser. Now suppose we take a piece of wire and touch it to one plate of the condenser. Then we bring the other end of the wire up to the other plate of the condenser and just lightly touch it. Look at Fig. 15. Just at the instant we touch the second plate (short circuit it) we will see a small spark, providing the voltage of the battery that was formerly connected to it, was high enough.

Now how about this? There was originally no electricity, or electric charge in the condenser, as far as we knew. If we had *short-circuited* the condenser before we connected it to the battery we would not have been able to get a spark. The condenser apparently has taken some electrical energy from the battery, and has *stored it up,* until we wanted to release it. When we furnished a path over which the electrons on one plate could rush over to the other plate this electrical energy was released, and became used up by creating the spark and by slightly heating the short-circuiting wire.

It will be remembered there were more electrons stored on one plate of the condenser than on the other. Consequently we could mark the two plates of the condenser in the same way as the terminals of the battery, that is (plus) and (minus). Now suppose, instead of short-circuiting the condenser by a mere piece of wire, we had connected in this wire another extremely sensitive instrument for not only detecting a flow of current, but which could also indicate which way the current was flowing. (See arrows, Fig. 16.) At the instant the path between the two plates is completed the electrons rush around in the direction of the dotted arrows from the negative to the positive plate. Since there are more electrons on the negative plate than on the positive plate, they try to get where there is least crowding.

In their haste to get around, more of them get on the upper plate than can comfortably stay there. As a result the upper plate, which was formerly positive, becomes negative, and the lower plate, which was formerly negative, becomes positive. But the lower plate is now *less* positive than the upper one was before, and the upper plate is now *less* negative than the lower one was before. However, the electrons *discharge* again, this time going in the other direction, and go through the whole process many times.

If we continue to hold the short-circuiting wire in place the same thing will occur again and again; the electrons oscillate back and forth, the polarity of the condenser reverses

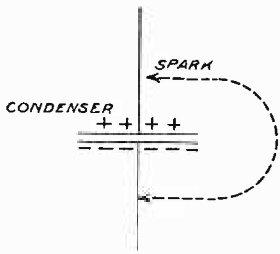

Fig. 15.

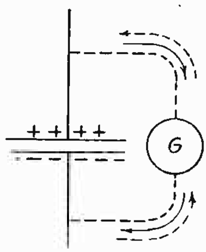

Fig. 16.

each time, and its voltage becomes less and less, until finally all the energy is converted into heat in the wiring and the voltage is zero, whereupon the condenser is totally discharged.

If you will remember, we stated in Lesson No. 1 that a flow of electrons is the same as a flow of current, and the direction in which the electrons flow determines the direction of the current. So we have in Fig. 16, a rapidly changing current, first flowing in one direction and then in another, continually growing less and less. This is a true Radio current, the *oscillating current* we spoke of in the first lesson. Each reversal of the current is called an *oscillation*. These reversals, or oscillations, take place very rapidly, each one requiring perhaps only a millionth of a second. The reason they finally die away is because their energy is gradually used up as they travel back and forth, as there is no battery or generator in the circuit of Fig. 16 which can supply it with energy to take the place of that consumed.

So now we have an oscillating current, although this oscillating current dies away quite rapidly. Furthermore, this current is quite small in the circuit we have just described. However, if we can find a means of preventing the current from dying away so rapidly perhaps we can make some practical use of it. Besides that, we can find a way of making this current oscillate at any particular rate that pleases us. In other words, we should be able to tune the circuits just like we tuned the violin string.

You remember in the paragraph given heretofore, that the electrons rushed from one plate to the other, during the discharge, with such zeal that the polarity of the condenser was reversed. Perhaps, if we slowed down the electrons in their rush, dampen their ardor, so to speak, we could delay the reversal of polarity.

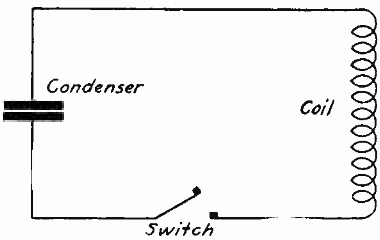

Fig. 17

This is exactly what we do in Radio circuits; it is in this way that we tune the circuits. By delaying the discharge of a condenser we can make the reversals as slow as we please, that is, we can make the frequency anything we want, by delaying the discharge in the right amount. We do this by placing in the circuit along with the condenser, a coil of wire.

Look at Fig. 17. In this circuit we have a condenser which we will assume is charged. We also have a switch, which is open, and a coil in series with the two. Let us close the switch and see what happens.

At the instance on closing of the switch the electrons rush out of one condenser plate in order to get on the other. But before they can get to their destination they have to pass through the coil. Now, you know when they pass through the coil, they establish a magnetic field, and it takes energy to do this. So they are retarded in their flight, and the electrostatic energy which they had while on the plate of the condenser becomes converted into electromagnetic energy in the coil.

When all their energy is thus converted and the magnetic field of the coil has attained its greatest strength, this field begins to collapse, for you know it requires a *movement* of electrons (or a current) to maintain an electromagnetic field in the coil. So the coil begins to give back to the circuit the energy it had taken from it. The electromagnetic energy is converted back into electrostatic energy, and the electrons finally complete their journey, reversing the polarity of the condenser.

Then they start all over again, and begin to discharge in the opposite direction. The coil again retards them, and the magnetic field is again established, but this time *its* polarity

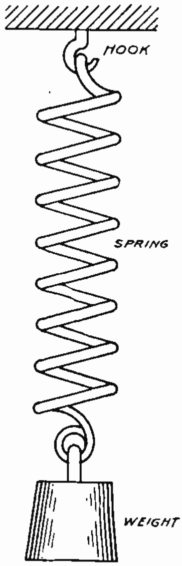

Fig. 18.

is reversed, for the discharged current is now flowing in the opposite direction. So the reversals continue, until finally they die away as they did before. This time, however, it took a great deal longer for the oscillations to die away than it did when there was no coil in the circuit. The greater we make this coil, that is, the greater the number of turns of wire, the slower will the reversals occur, and the longer will it take for the current to die away, *provided*—and this is important—provided that we do not increase the resistance of the circuit when we increase the number of turns on the coil. Resistance, you know, causes a loss of energy, and this would help to make the current die down rapidly. The only part of the electrostatic energy of the condenser, which the coil can turn into electromagnetic energy, is that part which is not converted into heat energy by the resistance of the circuit. Part of the resistance is in the coil, part in the condenser, and a small part in the connecting wires.

We can get the idea a little better perhaps by looking at Fig. 18. This illustration shows a heavy weight hung on a spring. Suppose we pull the weight down and let go. What happens? The weight *oscillates* up and down. But have you ever considered what goes on during this oscillation? When we pulled the weight down we had to exert a certain force, and this produced a tension in the spring, due to our stretching it. Now, when we let go of the weight, the tension in the spring pulls up the weight. In pulling up the weight, the spring gives up all of its energy excepting a small part, which is lost in friction with the air. The weight finally gets to the top of its journey and no longer moves upward. It is clear that since the spring no longer pulls the weight upward that it has lost all of its energy. Where has this energy gone? The answer is, all the energy that was not lost in friction has been given to the weight. It is clear that this must be so, for at that instant the weight begins to move downward, due to its *weight*. In moving down, the weight gradually returns its energy to the spring by stretching it, for soon the weight stops moving downward as the spring is stretched to its limit and then moves upward again, repeating the whole process. But gradually the system oscillates more and more slowly until finally it comes to rest, after all the energy in the system has been used in friction with the air, or from other causes.

The coil and condenser act in a very similar manner, as we have seen. The tension in the spring may be likened to the charge (or voltage) of the condenser. The original charge which we gave the condenser (see Fig. 14) takes the part of the *pull* we gave the weight when we started it oscillating. The coil takes the part of the spring. The up and down motion of the spring and weight is like the to and fro motion of the electrons in the electric circuit.

Now that you have finished Lesson 2, lay down this textbook for a moment and review in your mind what you have read. Recall the three fundamental measurements of electricity; the ampere, the ohm, the volt. What do each of these represent? Go over the lesson mentally as far as possible.

Then take up the lesson again, and be sure you have not missed any of the important principles. Now you are ready to answer the Test Questions on this page.

TEST QUESTIONS

Number Your Answer Sheet 2—3 and add Your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What is an electrical conductor?
2. Name several insulators.
3. How do we find the current in a circuit when we know the pressure and the resistance?
4. What is the resistance of a circuit when the voltage is 8 volts and the current is 2 amperes?
5. What is the purpose of a rheostat when used in the filament circuit of an electron tube?
6. How many times greater is the resistance of iron wire than that of copper wire?
7. Draw a diagram showing how a six volt storage battery, a rheostat and the filament of an electron tube are connected together so that the rheostat will control the current flowing through the tube.
8. Draw a diagram showing how a battery, one rheostat and the filaments of four electron tubes are connected in parallel so that the rheostat will control the current flowing through the four tubes.
9. Show by a drawing how several pieces of electrical apparatus are connected in series.
10. Why do the oscillations finally die out in the discharge of the condenser in Fig. 16?

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