RADIO AND TELEVISION INSTITUTE INC.

Practical Home Training in All Branches of Radio, Television and Talking Pictures

GENERAL WORK SHEET 19

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Radio Tubes—Their Characteristics and Operation

In one of the early work sheets I told you a little bit about a radio tube. Now I am going to tell you a whole lot more about it. It would be hard for me to tell you how important the tube is to radio because without it, modern radio simply would not exist.

The tube as we know it today did not happen all at once. No one man invented all of it. The beginning came about somewhat as I have shown it in Fig. 1. Back in 1884 Edison, the scientist, was experimenting. He had a lighted filament inside of a glass bulb from which nearly all the air had been exhausted. Inside the bulb was another wire. This second wire was not heated but was connected to the positive side of a source of voltage and the negative side of that source was connected to the filament.

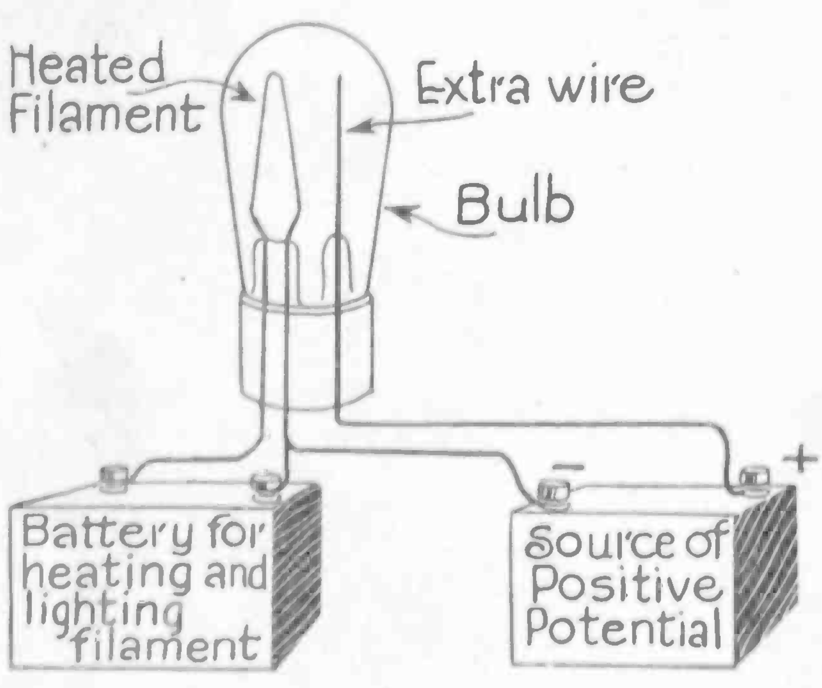


Fig. 1.

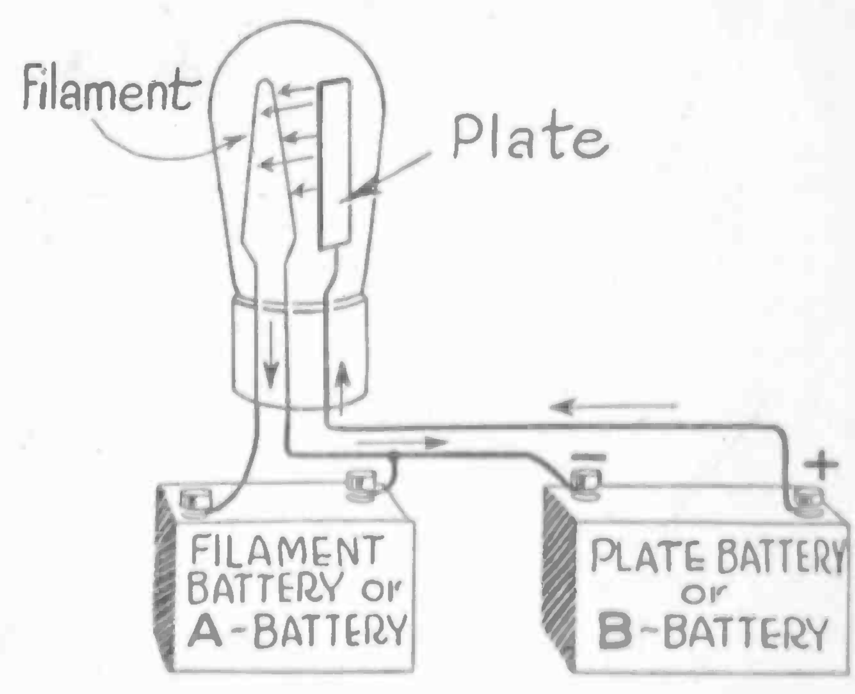


Fig. 2.

Mr. Edison found that current flowed from the extra wire right through the vacuum inside the bulb and over into the heated filament as I have indicated in Fig. 2. This current then passed back into the battery or other source of voltage attached to the extra wire. This was the beginning of our radio vacuum tube.

In Fig. 2 the direction of current flow is shown by the small arrows. It starts out from the positive terminal of the plate battery or, as we generally call it, the "B-battery". This current then flows to the extra part in the tube, which is shown as a flat metal plate in Fig. 2. The current leaves the plate, passes through the space between it and the filament and then flows through the filament. The filament battery or the "A-battery" and the "B-battery" are connected together and current which has passed through the plate comes back to the negative side of the B-battery, thus completing its circuit.

THE TWO-ELEMENT TUBE.

The filament is called one of the tube's "elements". The plate is another element. Consequently we call a tube having a filament and a plate a two-element tube. Such a tube is shown in Fig. 3. The filament is here a straight wire. The plate is a cylinder of metal placed around the filament. These two elements are connected to pins or prongs on the base of the tube. Tubes of this general type have been used as detectors, but since a later type makes a more efficient detector, you seldom find the two-element tube used in this manner nowadays. You will, however, find that a large proportion of our present rectifier tubes are of the two element type. A rectifier changes alternating current to direct current.

In the two element tube there are two things which we may change in securing a change in the amount of current flowing in the plate circuit. One of them is the voltage applied to the plate. The greater the positive voltage on the plate, or the greater the difference in voltage between the plate and the filament, the more current will flow.

The other thing which we may change is the heating of the filament. If the filament is cold no current whatever will flow between the plate and filament. As the filament is gradually heated it will reach a temperature at which a little current will flow. More and more heat allows more and more current to flow and as the filament lights up more and more brightly the plate current will increase. After the filament reaches a certain high temperature, the plate current no longer increases in proportion to the heat and beyond a certain point increasing the filament temperature causes practically no further increase in plate current.

Now we are going to get ready to add a third element, the grid. This third element is the one which allows the tube to amplify or strengthen radio signals and to do many other remarkable things.

FILAMENT EMISSION.

I told you that no plate current will flow until the filament is heated. There must be some good reason for this effect. There must be something different within the bulb when the filament is hot than when it is cold.

In Fig. 4 we have three pieces of filament wire, greatly enlarged. The one at the left is supposed to be cold, the one in the center is quite hot and the one at the right is very hot.

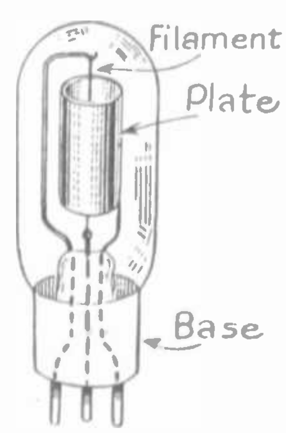


Fig. 3.

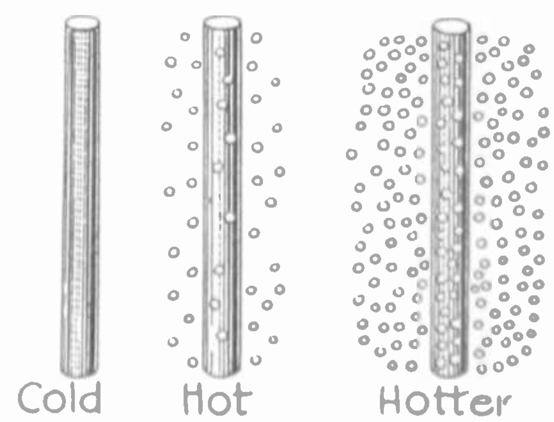
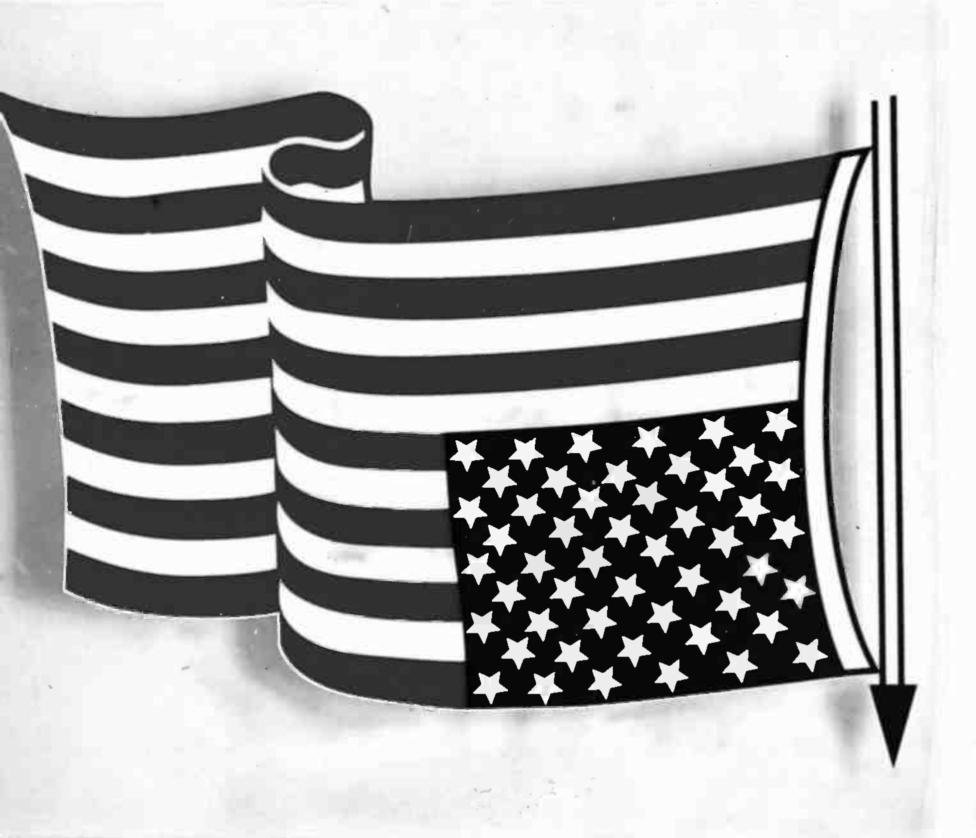


Fig. 4.

Nothing in particular happens in the space around the cold filament. But around the hot one a very peculiar action is taking place. This hot filament is sending out from its surface the things we call "electrons". The electrons fly out for a little distance, then fall back into the filament.

The very hot filament is also sending out or is emitting electrons, but it is sending out many more than before it became so highly heated and the emitted electrons travel away from the filament to a much greater distance before they again fall back.

Now you are going to say "What in the world is an electron?" In Fig. 4 I have represented electrons coming out of the filament, but I can't draw a picture of a real electron. No one has ever seen one and no one ever will see one An electron is the smallest thing in existance.



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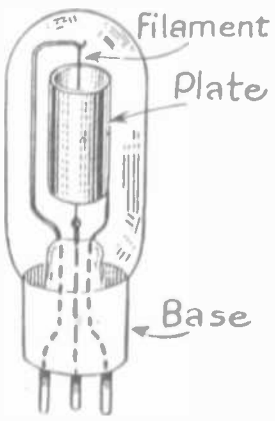
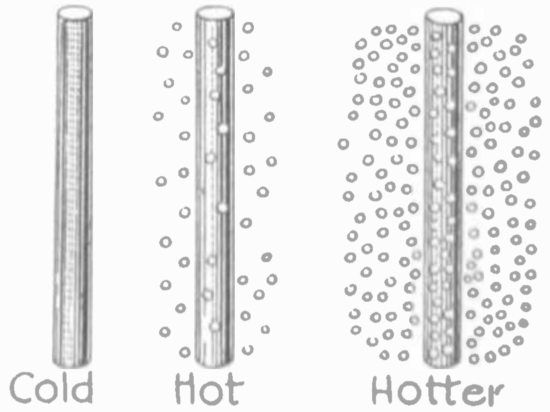


Fig. 3.



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ELECTRONS.

Of course you know that any common substance may be divided into smaller and smaller particles. Take salt, for instance. You can pulverize the salt as fine as you will and you still have salt. The smallest possible piece of salt would be called a "molecule" of salt.

You could take that molecule of salt and by chemical action you could break it down into two other things. One would be the metal sodium and the other would be the gas chlorine. In place of salt you would now have one "atom" of sodium and one atom of chlorine. For years and years the scientists believed the atom to be the smallest division of matter. They considered that the various kinds of atoms were the materials of which everything was made up by combining the atoms in different ways.

Now we know that the atom is not the smallest thing in existance. The smallest thing is an electron. Two or more electrons in combination with what is called a "positive nucleus" form an atom. An electron is electricity itself, it is a particle of negative electricity or is a negative charge.

You can't possibly realize how small is one electron. If you had a ball or sphere of copper so small that 100,000 of them laid side by side would extend one inch it would be something pretty small. Yet in each one of those balls of copper there would be twenty billion (20,000,000,000) electrons.

Hydrogen gas is one of the lightest of all things in weight. It would take two hundred fifty million (250,000,000) hydrogen atoms in a row to make a length of one inch. And yet every one of those hydrogen atoms would weigh two thousand times as much as an electron.

What I want you to remember out of all this is that an electron is negative electricity. A proton is positive electricity. We are going to study electron flow.

ELECTRON FLOW.

Remember that the plate in a tube is at a higher potential than the filament, the plate is positive and the filament is negative with respect to each other. Anything which is positive has an attraction for something else which is negative, the positive body exerts an attraction on the negative body and they tend to come together.

When you were younger you probably played with a magnet and a small compass, the kind of a compass that tells which direction is north. Then you found that the positive end of the magnet would attract the negative end of the compass and that the positive end of the compass was drawn toward the negative end of the magnet as in Fig. 5.

The same sort of attraction exists between the positive plate and the negative electrons which are emitted by the hot filament. The electrons are negative electricity

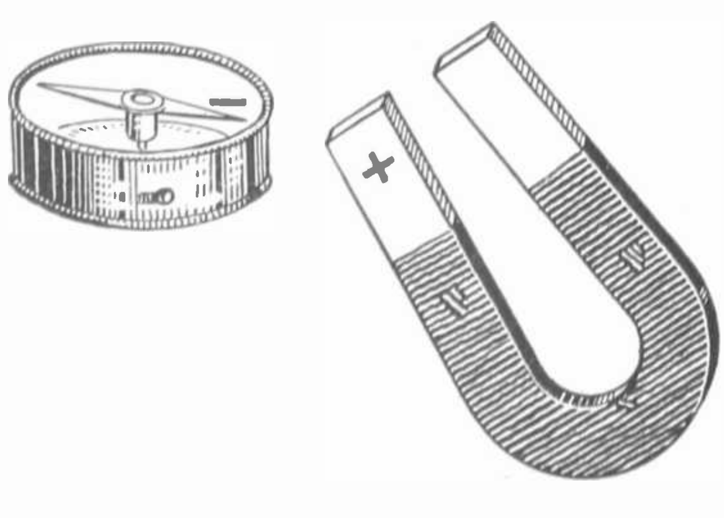


Fig. 5.

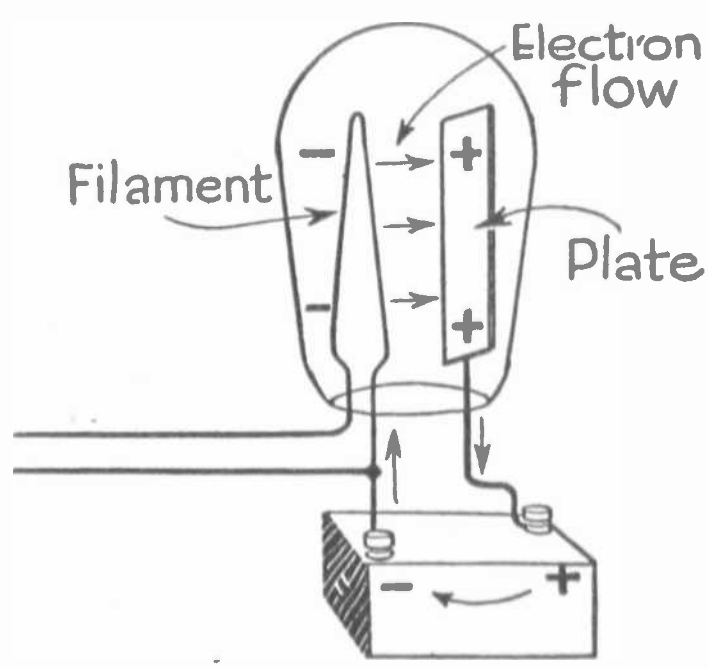
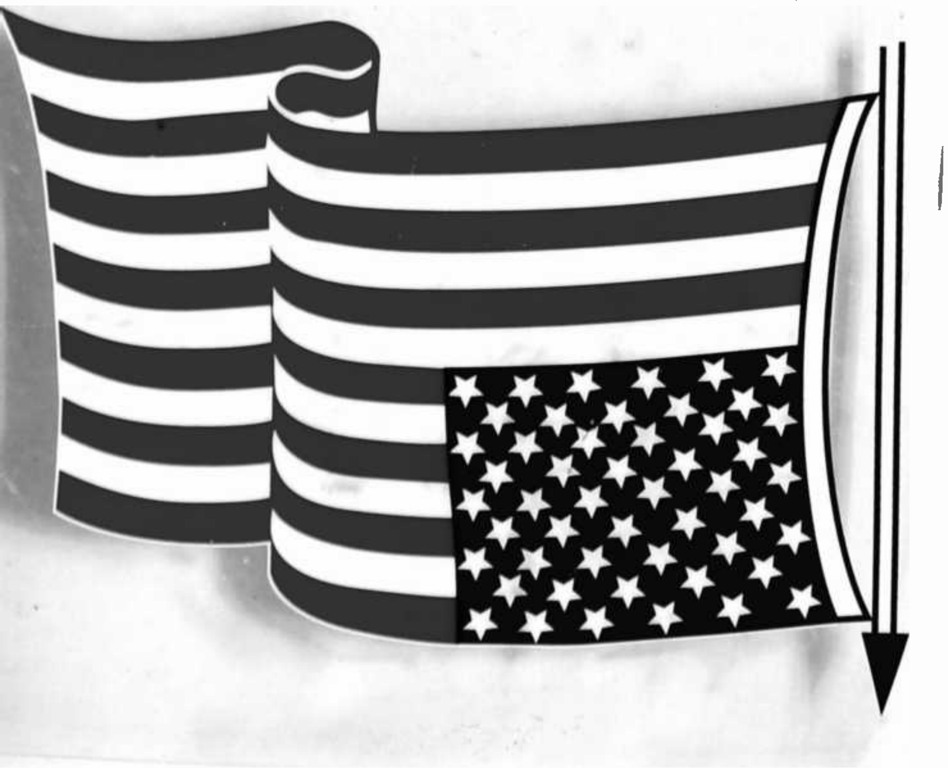


Fig. 6.



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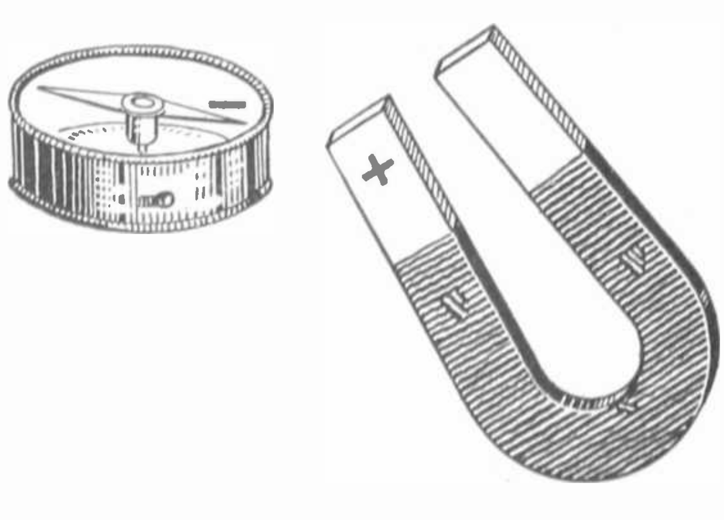

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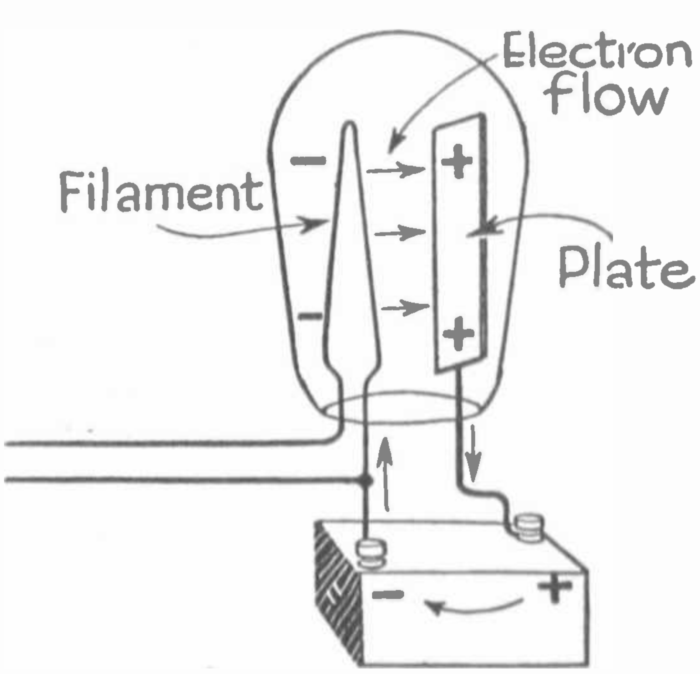


Fig. 6.

and are attracted to and are pulled over to the positive plate as indicated in Fig. 6. As shown by the small arrows between filament and plate, the electrons leave the filament after being released by the heat, get caught by the plate's attraction and some of them fly across and enter the plate.

The electrons which travel across the space and get into the plate flow down through the wire to the plate battery, go through the battery and then go back into the filament at the connection between plate battery and filament battery.

If you will compare Fig. 6 with Fig. 2 you will see that the electric current is flowing from the plate to the filament, but that the electron flow is from filament to plate -- just the other way around. It's too bad we can't think of current and of electrons as flowing in the same direction. The flow of current from plate to filament is what we call a "convention" -- it is just an idea, or something assumed as being true by those who first worked with electricity. The fact of the matter is that electrons, which are really negative electricity, pass from the heated filament to the positive plate. We also have to assume, because it always has been assumed, that the current flows the other direction.

The two filaments in Figs. 7 and 8 are both heated to the same degree and both are emitting the same quantity of electrons. In Fig. 7 only a small voltage is applied to the plate, say that the plate potential is about twenty volts above that of the filament. The plate has a rather weak attraction for the electrons which form a cloud around the filament and only a few of these electrons are attracted over onto the plate. In Fig. 8 conditions are different. The plate voltage is much higher, say it is ninety or one hundred volts. The filament isn't emitting any more electrons than before but now the plate exerts a very strong attraction and many more of the electrons are drawn away from the space around the filament and pulled over to the plate.

Increasing the plate's voltage causes a greater electron flow just as it causes a greater flow of current. You will find this true always; electron flow and current flow obey the same laws and obey them in the same way.

When electrons leave the filament because of its heat, a certain amount of negative electricity has been removed from the filament. Therefore the filament is left more positive than before the electrons left it. Since the filament is then positive with respect to the electrons in the space around it, the electrons that aren't drawn over to the plate are attracted by the filament itself and fall back into the filament.

The cloud of electrons around the hot filament is called the "space charge".

Now I am ready to fulfill my promise to show you how the grid works. I couldn't do so until you understood about the electrons because it is on the electrons that the grid does its work.

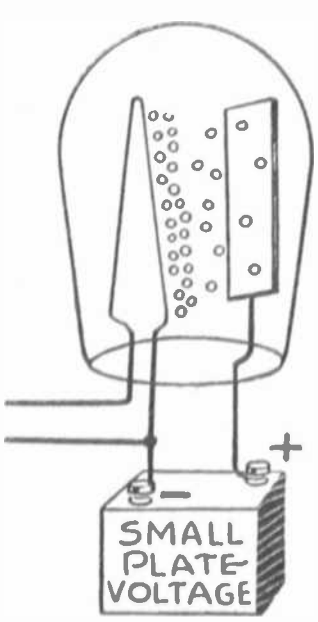


Fig. 7.

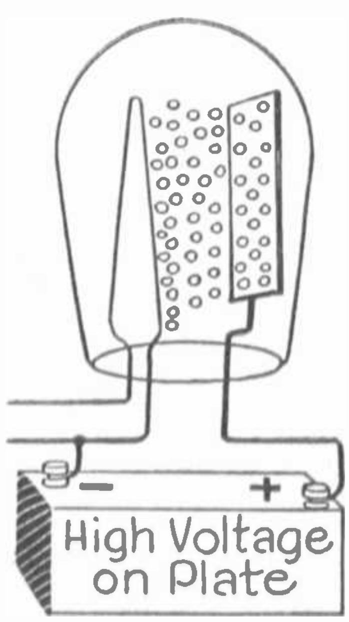


Fig. 8.

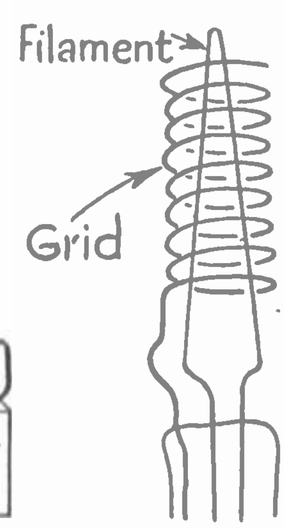


Fig. 9.

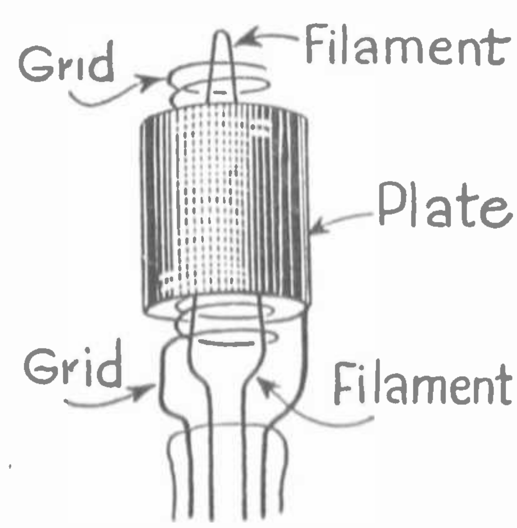


Fig. 10.

HOW THE GRID CONTROLS THE TUBE'S ACTION.

Up to this time we have been using two elements in our tube. Now we will add a third. In Fig. 9 you will see the usual filament and coiled around it another wire, the grid. The grid winds around and around the filament. At its lower end the grid is attached to one of the tube's prongs or pins, but the upper end is left without electrical connection, it just sticks up into the space around the filament but does not touch it.

In Fig. 10 the plate has been put around the outside of the grid so that, from the inside, we first have the filament, then the grid and finally the plate. This is the way the three elements are actually arranged within the tube. In order to explain the grid's action it is convenient to show the three elements as in Fig. 11. Here again the grid is between the filament and the plate, so this symbol for a three-element tube really shows the relative positions of the parts.

Looking back at Figs. 7 and 8 you will recall that a space charge of negative electrons exists all around the heated filament. Once this space charge exists around the filament, it makes the emission of more electrons from the filament more and more difficult. I have already told you that positive and negative things attract each other and it is just as true that things alike in polarity repel each other. That is why the negative space charge repels the emission of any more negative electrons from the filament. Two negative charges repel each other, or try to keep away from each other. The same thing would be true of two positive charges, they too would repel.

Now look at Fig. 11. You see the grid is located right in the midst of the space charge. You also can see that the potential of the grid is higher than that of the filament because the grid is connected to the positive side of a small battery of which the negative side is connected to the filament. Therefore, the grid is positive and the filament negative. Whenever the grid is at a higher voltage than the filament we say the grid is positive.

The positive grid counteracts to some extent the negative space charge. The electrons leaving the filament find fewer negative electrons or a less intense negative space charge to oppose their emission. Therefore, more electrons leave the filament. The positive grid acts to some extent like the positive plate, it pulls the electrons away from the filament and makes it possible for the emitted electrons to fly out farther from the filament.

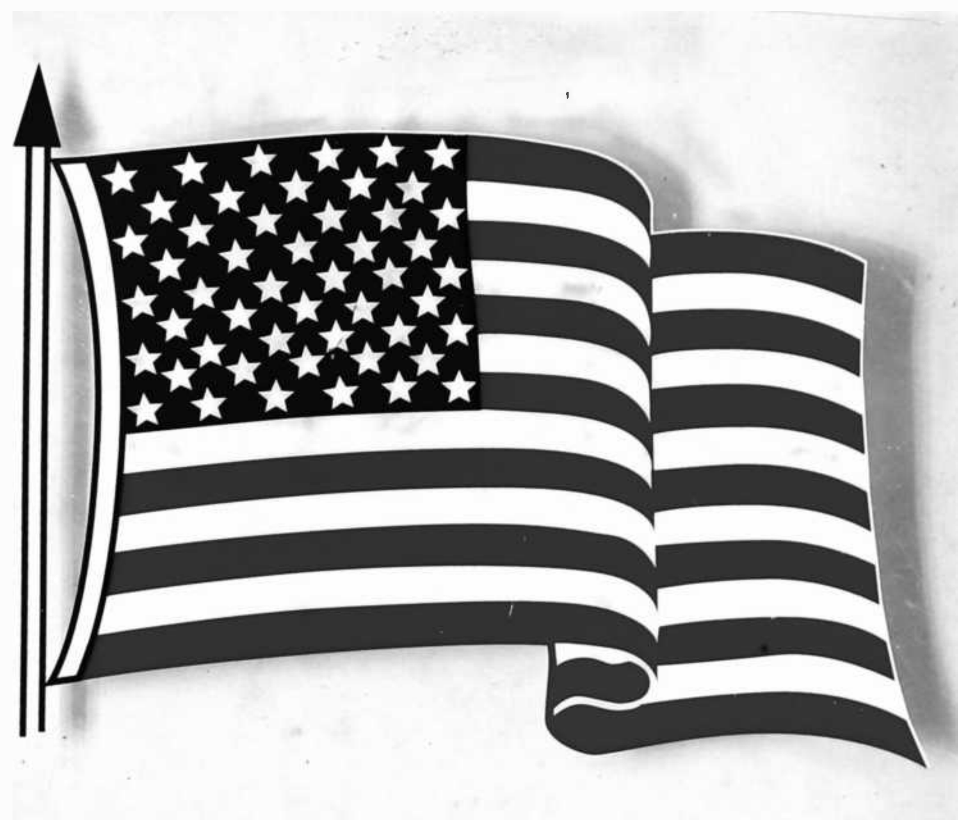
The plate in Fig. 11 is held at a positive voltage by the plate battery. The voltage of the plate is very much higher than the voltage of the grid. Once the grid helps the electons to get farther from the influence of the filament, the plate steps in with its still greater pulling power and lots of these electrons are drawn over to the plate.

Since the grid is positive it attracts some of the electrons to it, they reach the grid and flow around through the battery and back to the filament. At the same time a certain amount of battery current flows from battery to grid, across the space to the filament and through the filament back to the grid battery. Whenever there is an electron flow in one direction there is a corresponding current flow the other direction in any circuit.

The voltage of the grid is higher than that of the filament, but it is nowhere near as high as the voltage of the plate. The electrons reach the grid and reach the plate in proportion to the voltages of the grid and plate. Inasmuch as the plate has much the higher voltage, most of the electrons reach the plate and the grid gets only a few. The real purpose of the grid is to make it easier for electrons to get over to the plate when the grid is positive with respect to the filament.

In Fig. 11, with the positive grid, there are a great many electrons flowing in the plate circuit and a few electrons flowing in the grid circuit. There is a correspondingly large current flowing in the plate circuit and a small current flowing in the grid circuit.

Now look at Fig. 12. Here the grid is negative. It is at a lower potential than the filament because the grid is connected to the negative side of the small grid battery and the positive side of this battery is connected to the filament. When a



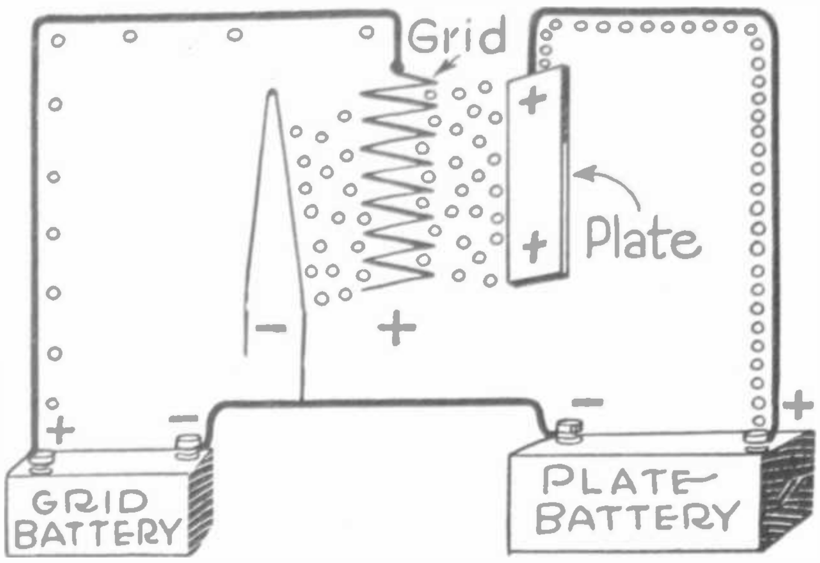


Fig. 11.

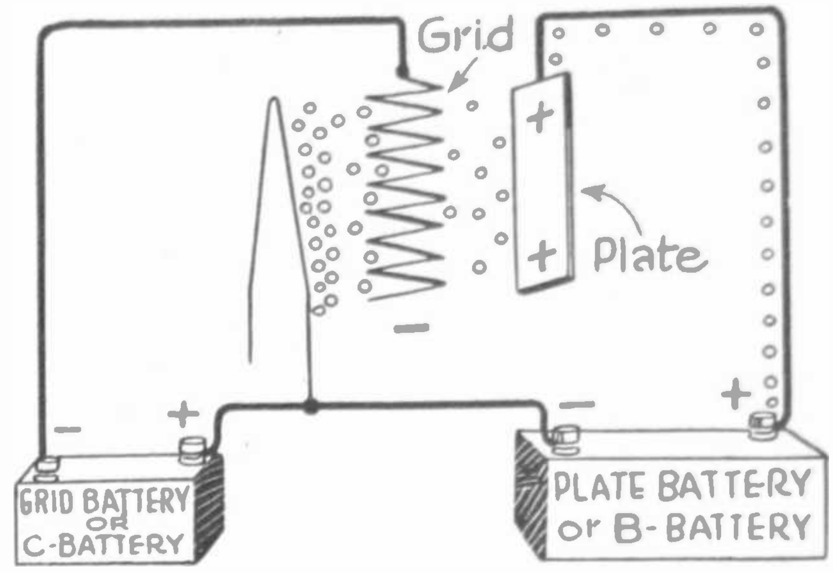


Fig. 12.

battery is connected in this manner, so that it keeps the grid's potential below the potential of the filament we call it a "C"-battery". Now we have a C-battery for the grid, a B-battery for the plate and an A-battery for the filament. In Figs. 11 and 12 I have not shown the A-battery because we do not need it for this explanation of grid action.

With the grid negative with respect to the filament, the grid's action is just the reverse of what it is with a positive grid. Now the negative grid adds its effect to the always present negative space charge and the electrons emitted from the filament find it more difficult than ever to get far from the filament. They meet not only the repelling effect of the space charge but the repelling effect of the negative grid as well.

The result of the negative grid is that only a few electrons get far away enough from the filament to be attracted to the plate. Of course, a few electrons do get through the grid because the plate voltage is still as high as ever and the plate exerts a strong attraction for the electrons. Now there are comparatively few electrons flowing through the plate circuit and there is a proportionately small amount of plate current.

Because the electrons themselves are negative and the grid is also negative, these two negative charges repel each other. The negative grid keeps the negative electrons from entering the grid and there is no electron flow and no current flow whatever in the grid circuit. When the grid is negative with respect to the filament there is never any flow of grid current.

GRID BIAS.

We call the voltage of the grid with respect to the voltage of the negative side of the filament the grid's "bias". In Fig. 11 the grid has a positive bias. In Fig. 12 the grid has a negative bias.

In tubes having their filaments operating on direct current the grid bias is the voltage difference between the grid and the negative end of the filament. In Fig. 13 there is a C-battery of 4½ volts between the grid and the filament. The positive end of this battery is connected to the negative end of the filament or to the end of the filament which attaches to the negative side of the filament battery.

Since the negative side of the C-battery is 4½ volts lower in potential than this battery's positive side and since the grid is connected to this point of lower potential, the grid must be 4½ volts lower in voltage than anything connected to the positive side of the C-battery. Then the grid must be 4½ volts lower than the negative end of the filament. Here we would say that the grid has a 4½ volt negative bias. A voltmeter connected between the grid and the negative side of the filament will show the grid bias

In Fig. 14 the grid is connected directly to the negative side of the filament. Since these two parts are connected directly together they will be at the same

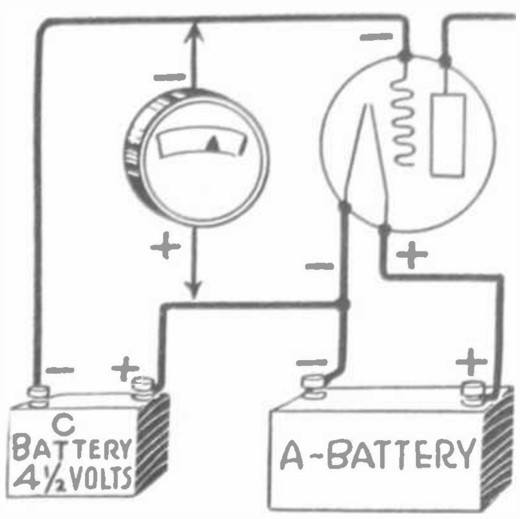


Fig. 13.

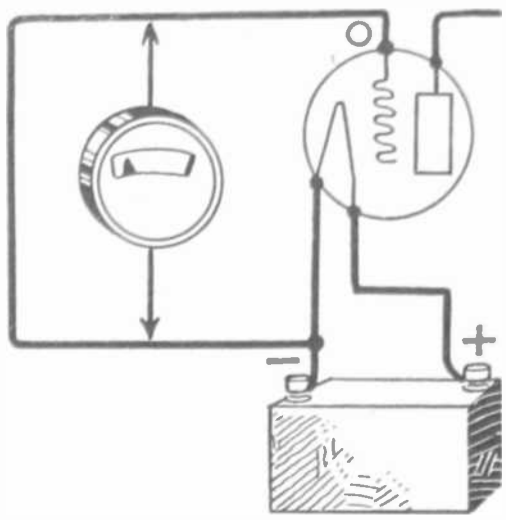


Fig. 14.

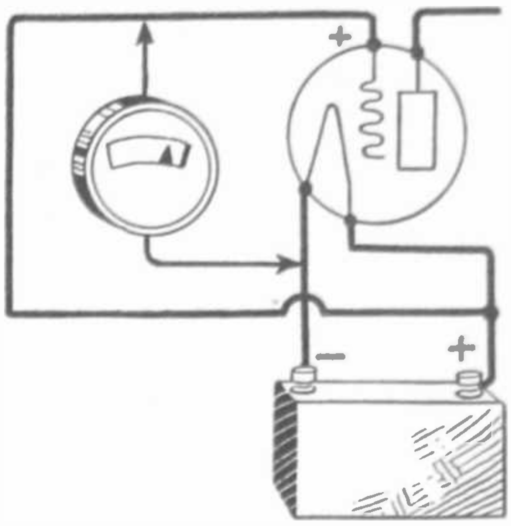


Fig. 15.

potential, there will be no potential difference and we say the grid has a "zero bias". A voltmeter between grid and negative filament would read zero because there is no voltage difference.

In Fig. 15 the grid is connected to the positive side of the tube's filament. This places the grid at a higher potential than the negative end of the filament because, of course, the positive end of the filament is at a higher voltage than its negative end. A voltmeter placed between the grid and the negative end of the filament would now show the grid at a higher voltage than the negative end of the filament and the grid would have a positive bias.

In these drawings illustrating different grid biases the tube is not doing anything in particular. A little later on we are going to give this tube various kinds of jobs, the first of which will be to amplify a signal. The signal will raise and lower the grid's voltage but it won't change the bias. We will have to make an addition to our definition for grid bias and say, grid bias is the difference between the grid potential and the potential at the negative end of the filament when no signal is being applied to the grid circuit.

OTHER NAMES FOR TUBE ELEMENTS.

We have been calling the part through which current (in the plate circuit) enters the tube by the name of "plate". The plate is often called the "anode" as marked in Fig. 16. One name is as correct as the other. The plate current leaves the tube by way of the filament and therefore, the filament may be called the "cathode". The grid has but one name.

In the tubes I have shown you so far the electrons are emitted from the filament or the cathode, these two names here referring to one and the same part. There is another kind of tube, the A.C. heater type, in which the cathode or electron emitter is separate from the part which supplies the heat. The construction of such a tube is shown in Fig. 17.

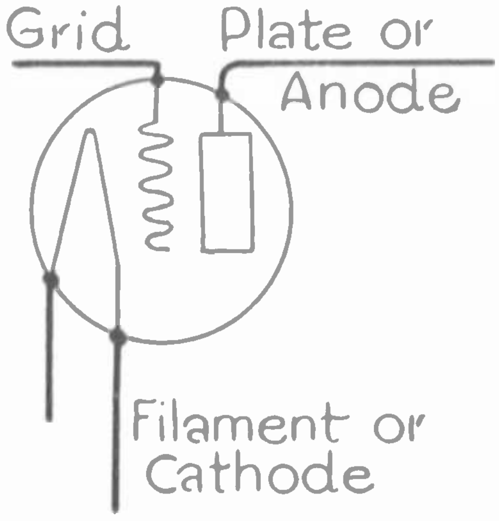


Fig. 16.

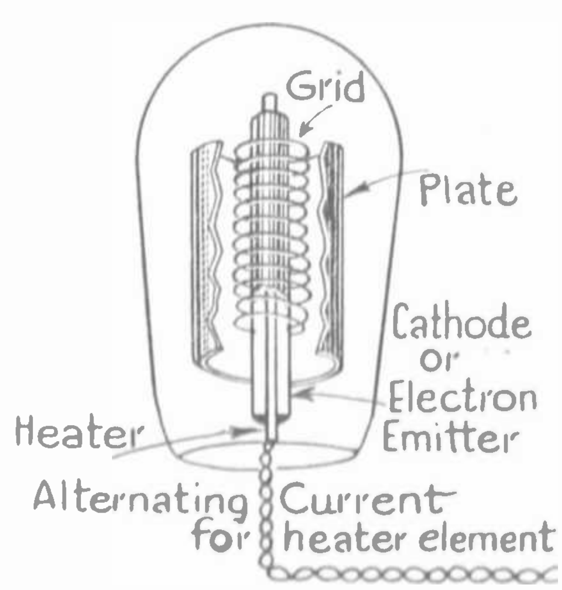


Fig. 17.

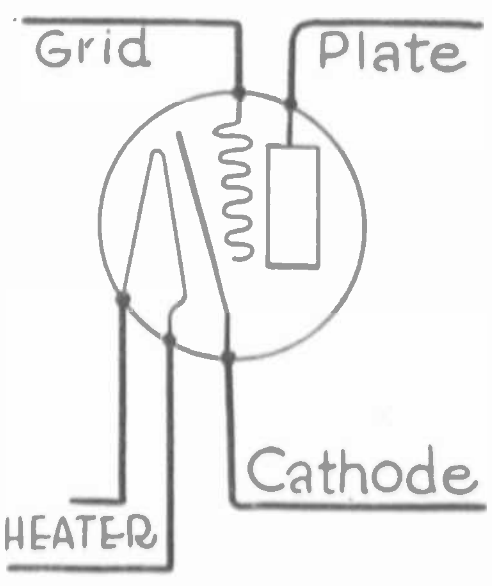
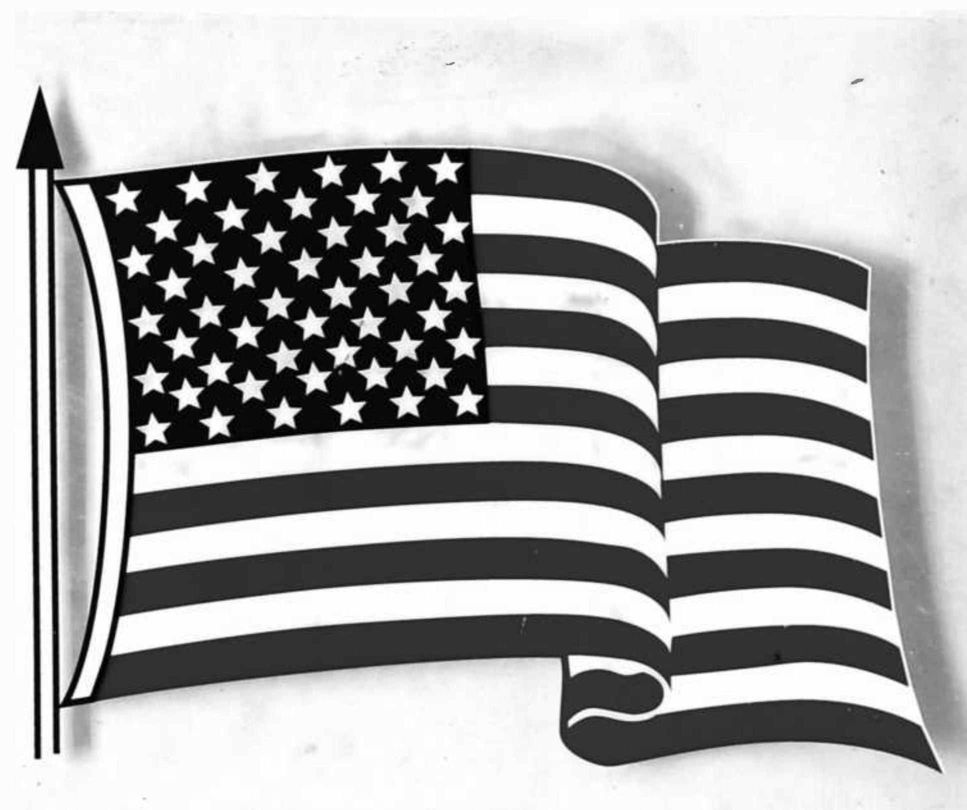


Fig. 18.



The plate and grid of the A.C. heater tube are the same as similar parts used in any other tube. But in the A.C. heater tube there is no filament which carries the heating current and at the same time acts as the electron emitter. Taking the place of the filament there are two other parts, a heater element and a cathode element. The heater contains wires through which flow of alternating current produces heat. Around the outside of the heater is the cathode, a cylindrical metal surface which is heated and which then emits electrons.

Whereas the tube construction of Fig. 17 is designed especially for use with alternating current it is also possible to use alternating current with which to heat the filaments shown in all the other illustrations. The heater type of tube is less apt to produce hum when used with alternating current than the filament type. There are certain jobs which are performed better by the heater tube and others which are performed better by the filament types. One symbol for an A.C. heater type tube is shown in Fig. 18. Other similar symbols are also used.

THE TUBE'S CIRCUITS.

In the filament type of tube the filament circuit includes the filament within the tube, the battery or other source of filament current and the wires connecting the two parts together.

The plate circuit of any tube includes all the parts through which the plate current flows. One plate circuit is shown in Fig. 19. It includes the battery or other source of plate current, it includes any coils or resistances between the source and the tube's plate, it includes the plate itself, the space within the tube, the filament through which the current returns to the source and all the wires which connect these parts together. In following the plate current from its source all the way around and back again to the source you will have followed the plate circuit.

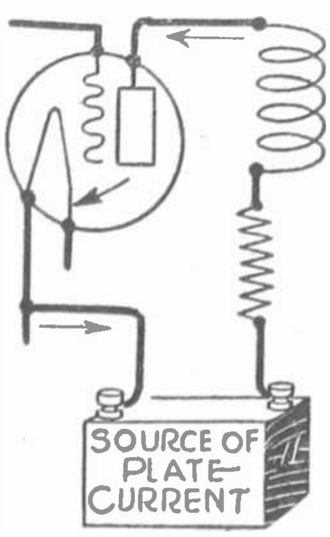


Fig. 19.

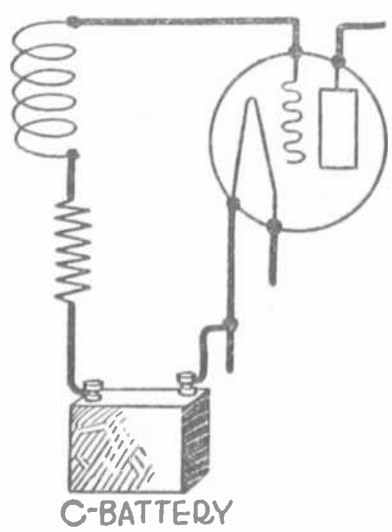


Fig. 20.

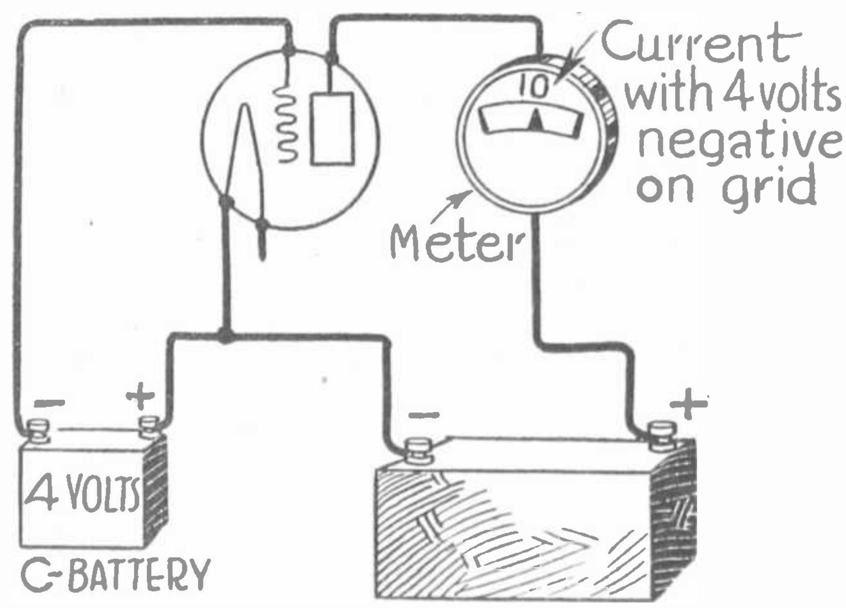


Fig. 21.

The grid circuit of a tube includes all the parts between the grid and the filament as shown in Fig. 20. This particular grid circuit takes in the grid, then the coil, then the resistor, then the C-battery, then the filament, and it also includes the space within the tube and all the wires used to connect the other parts together. In A.C. heater tubes the cathode takes the place of a filament as far as these circuits are concerned.

WATCHING THE GRID DO ITS WORK.

In Fig. 21 you will see a tube with a 4-volt C-battery in its grid circuit and with a milliammeter in its plate circuit. We will say that the B-battery voltage applied to the plate is such that the 4-volt negative grid bias allows a current of 10 milliamperes to flow in the plate circuit. The word "milliamperes" is a rather long one so radio men generally speak of "mils" in place. Hereafter, when I say so many mils you will know that I mean that number of milliamperes.

You know that changing the voltage of the tube's grid will cause a change in the amount of current in the plate circuit. You know that the more strongly negative

the grid is made the less current will flow in the plate circuit. Of course, making the grid less negative will reduce the repelling action on the emitted electrons, more of them will flow and there will be a larger plate current.

We are going to change the grid's potential by changing the amount of bias. In Fig. 22 you see the same circuit as in Fig. 21 with the addition of another small battery, the one marked "extra voltage." This is a 2-volt battery.

Now look very carefully. In Fig. 22 the grid is connected to the negative terminal of the extra voltage. The grid was 4 volts negative to begin with because of the C-battery. Now we have made the grid still more negative by this extra 2 volts. So the potential of the grid is now 4 volts plus 2 volts, or 6 volts below that of the negative end of the filament. Making the grid more negative allows less flow of plate current and we find that the milliammeter now reads only 7 mils.

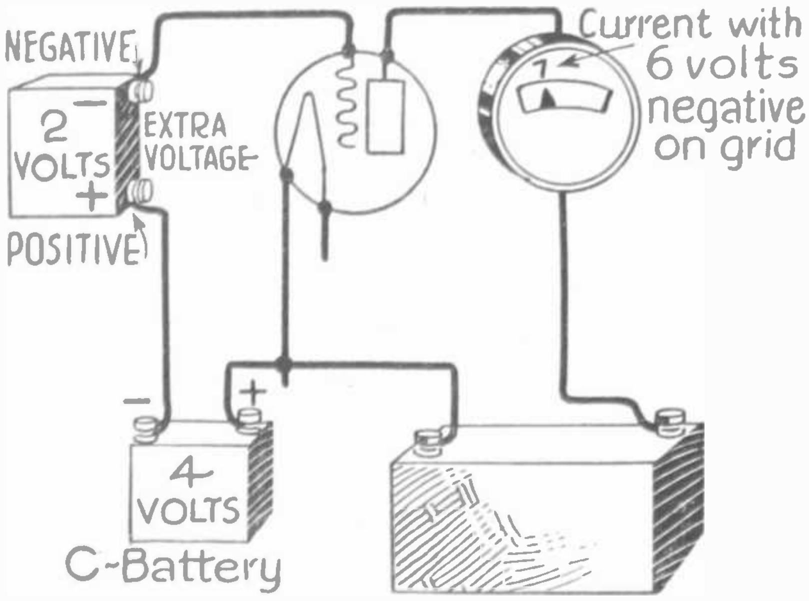


Fig. 22.

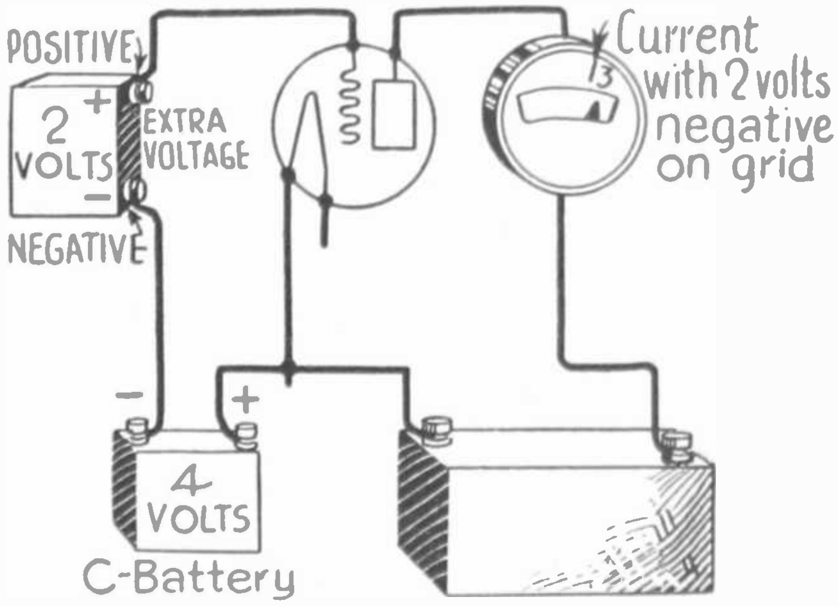


Fig. 23.

Next, look at Fig. 23. We have just the same parts as in Fig. 22 but the small battery giving the extra voltage has been turned end for end. Now the tube's grid is connected to the positive end of this extra voltage. Does that make the grid positive? No, it does not.

Remember that the 4-volt C-battery is there in the grid circuit all the time. All that the extra positive voltage applied to the grid is really doing is lessening the negative voltage of the C-battery. The 2 volts extra is taken away from the original 4 volts negative bias so that the grid is now only 2 volts below the negative end of the filament in potential. That is, the grid is now only 2 volts negative.

With the grid only 2 volts negative it does not oppose the flow of plate current nearly as much as when it was 4 volts or 6 volts negative and upon looking at the milliammeter we find that the plate current has increased to 13 mils.

Making the grid voltage more or less negative has changed the amount of plate current flowing. Notice particularly that, because of the C-battery, the grid's potential has always been below that of the negative end of the filament. The grid's voltage has changed, but all the changes have been on the negative side. It gets more or less negative, but it never goes over on the positive side with respect to the filament's negative end. The tube is "worked" with a negative grid potential at all times so that no current will flow in the grid circuit and so that all the electron flow will be in the plate circuit.

From what you have seen in Figs. 22 and 23 it is perfectly evident that any extra voltage applied to the grid circuit will cause the plate current to change in step with all changes in the amount of this extra voltage.

The illustrations I have just used brought out the fact that the plate current changes with changes in grid voltage, yet you did not really see a very clear picture of just how much effect the grid voltage had on the plate current. There is a way of letting you see these changes very clearly. It is by means of "graphs" or curves.

THE ENGINEER'S PICTURES.

You often have watched the liquid in a thermometer rise and fall with changes in temperature. The liquid changes its length. You could draw straight lines which would correspond to the length of the thermometer's liquid just as I have drawn them in Fig. 24. One line represents a temperature of 20 degrees above zero, another represents zero, a third represents 50 degrees above zero and the last one corresponds to 20 degrees below zero.

Suppose you started in at one o'clock some morning during cold weather and at each hour you drew a line corresponding in height to the height of the liquid in the thermometer at that hour. You might start off with 20 degrees above zero at one o'clock as in Fig. 25, then at two o'clock mark off 15 degrees above, at three o'clock make a line standing for 10 degrees above, at four o'clock make one representing zero and so on as I have shown the lines all the way through to twelve o'clock.

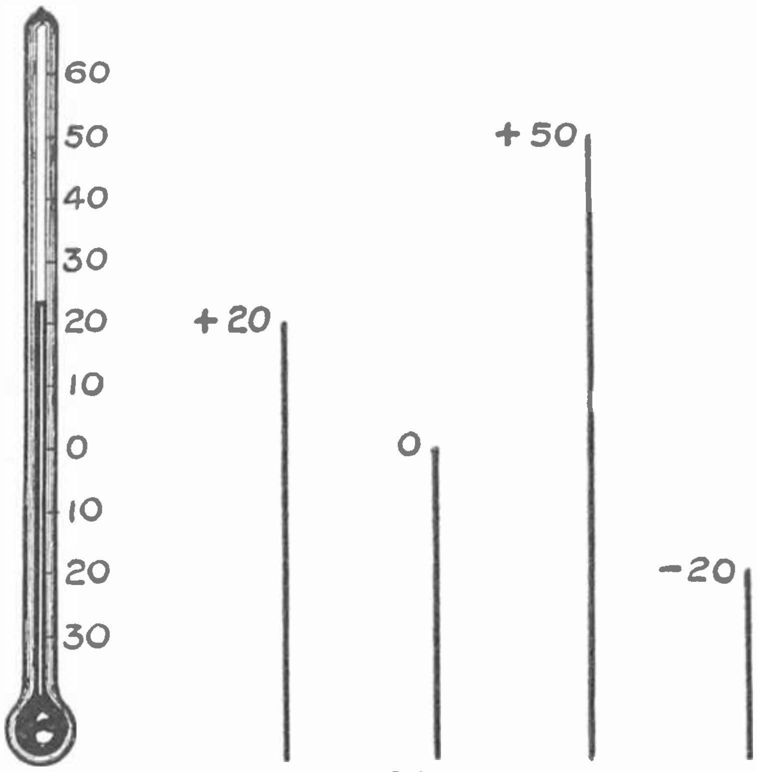


Fig. 24.

Anyone looking at Fig. 25 could tell exactly how the temperature changed with the changing hours during that time. Still, this method is not simple and clear enough. It is only the position of the tops of the lines that counts, so you might draw a line connecting all these tops together. The vertical lines are no longer of any use because the single new line tells the whole story; accordingly we will erase the vertical lines and leave the single line as in Fig. 26. We have drawn a graph or a curve showing the relation between hours of time and degrees of temperature. With only a glance you can tell instantly that the temperature dropped to its lowest point near the middle of the period, was higher at the beginning and end, and was higher at the end than at the beginning.

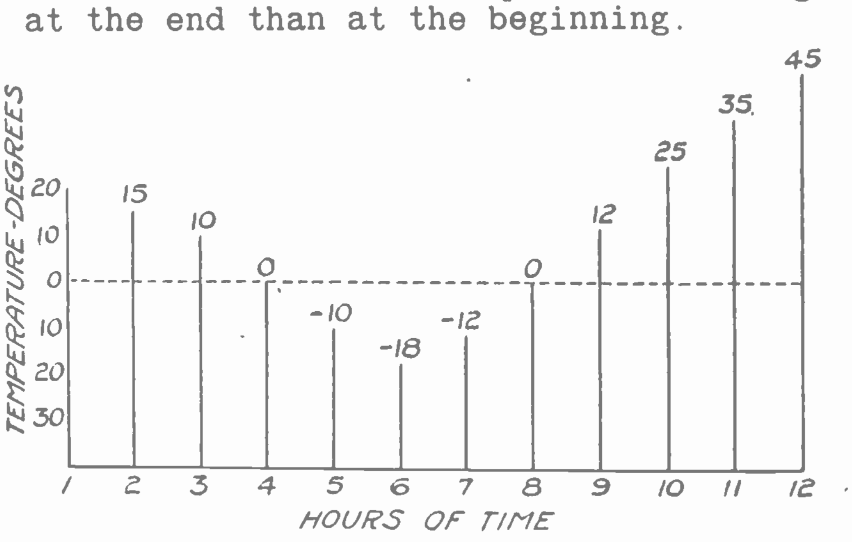


Fig. 25.

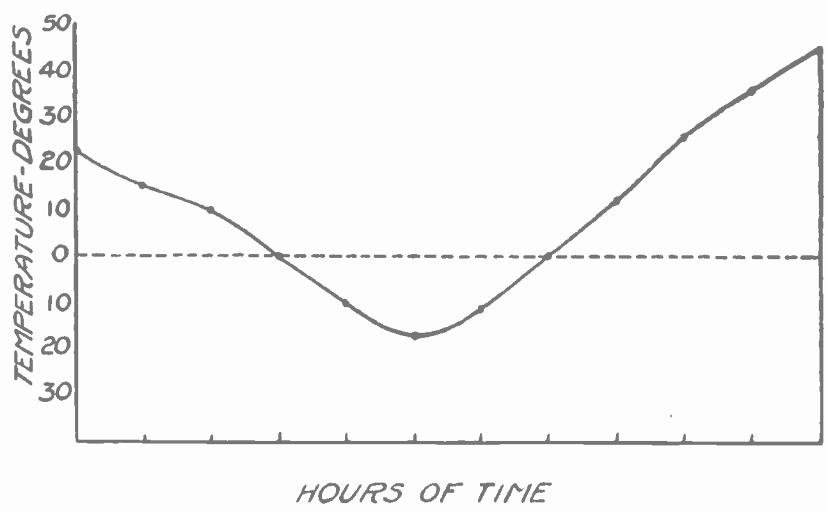


Fig. 26.

Let's draw a graph telling the story of Figs. 21, 22 and 23. In Fig. 27 the horizontal or crosswise lines indicate the number of milliamperes from zero (0) up to 15. They are equally spaced and divide the vertical lines into 15 equal parts. The vertical or up-and-down lines indicate the number of volts on the grid from zero (0) at the right down to negative 8 or minus 8 at the left. The three circles are placed where the lines cross for grid voltages and plate currents that we know. Then these three circles are joined by a single line which shows the effect of changing grid voltage on the flow of plate current.

In Figs. 21, 22 and 23 we took readings with only three different voltages, with 2 volts, 4 volts and 6 volts negative. Suppose you want to know how many mils will flow with negative five volts on the grid. Look at Fig. 27 where I have drawn a broken line at the 5-volt position. It crosses another imaginary crosswise line at the position for 8½ mils and you can be sure that 8½ mils will flow in the plate circuit when the grid is held at negative 5 volts.

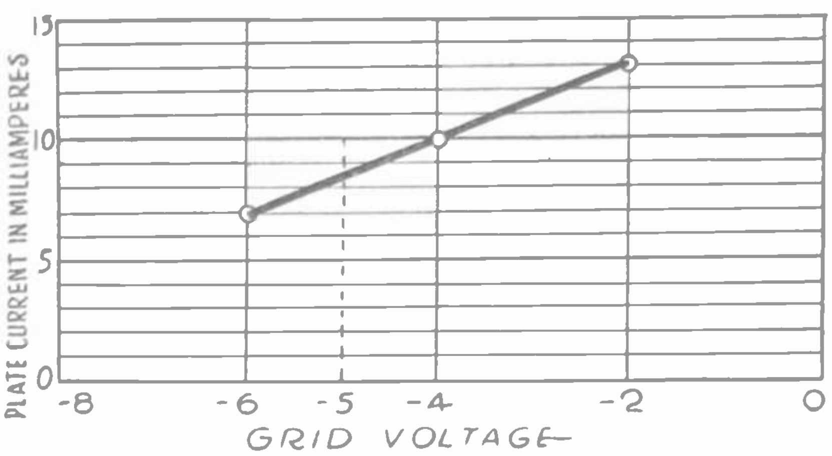


Fig. 27.

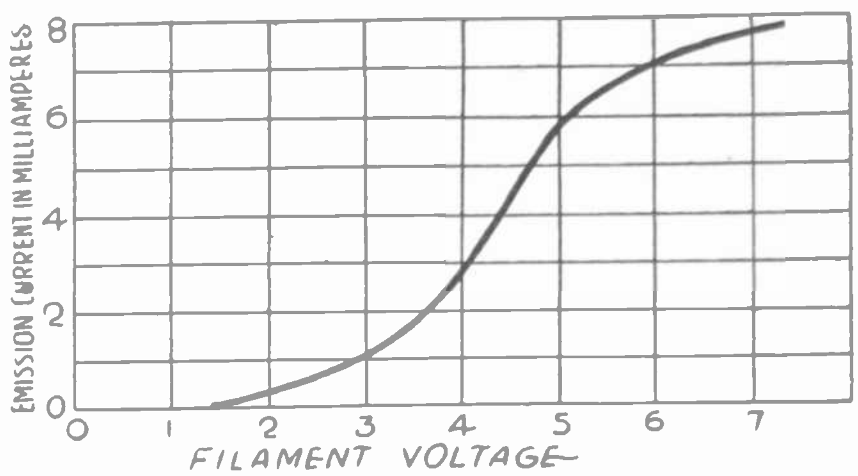


Fig. 28.

There is no end to what you can determine from looking at a graph. A ways back I told you that heating the filament above a certain point would have very little effect on the electron emission or on the flow of plate current. In Fig. 28 I have told you the same thing in a graph. The temperature of the filament depends on the amount of current you send through it and the amount of current depends on the amount of voltage you apply to the filament. The more the voltage, the greater the current and the higher the temperature. Fig. 28 shows the relation between the filament emission and the voltage put on the filament of a tube which normally requires 5 volts to operate it correctly.

The filament emission is measured in the number of milliamperes of current it allows to flow in the plate circuit. With a high plate voltage, the greater the emission the greater will be the amount of plate current. Notice that in Fig. 28 there is no emission at all until you apply nearly 2 volts to the filament. Then there is a very slow increase until you get to about 3½ volts. From that point the emission goes up more rapidly until, at 5 volts, it begins to increase less rapidly. From 4 volts to 5 volts the emission increased from 3 to 6 mils or an increase of 3 mils. But from 5 volts to 6 volts, the same voltage increase, the emission increased only from 6 mils to 7 mils or an increase of only one mil for the same increase in voltage. So you see, increasing the voltage above 5 volts does not help much with the emission. Do you also see what a complete picture of the whole process we get from an examination of the graph in Fig. 28?

Fig. 29 shows a graph of the actual relation between grid voltage and plate current in the type 56 A.C. heater tube, one of the most popular tubes. The plate milliamperes, from zero to 40, are arranged along the left hand edge. The grid voltages, from zero down to 20 negative are shown along the bottom edge. Zero grid voltage or zero bias is shown in a heavy line.

Notice that the plate current is more than 40 mils with zero grid bias. With a drop in grid voltage, with this voltage becoming more negative, the plate current drops sharply to a point where the grid is 12 volts negative, then drops less rapidly with further decrease of grid voltage. When we get down around

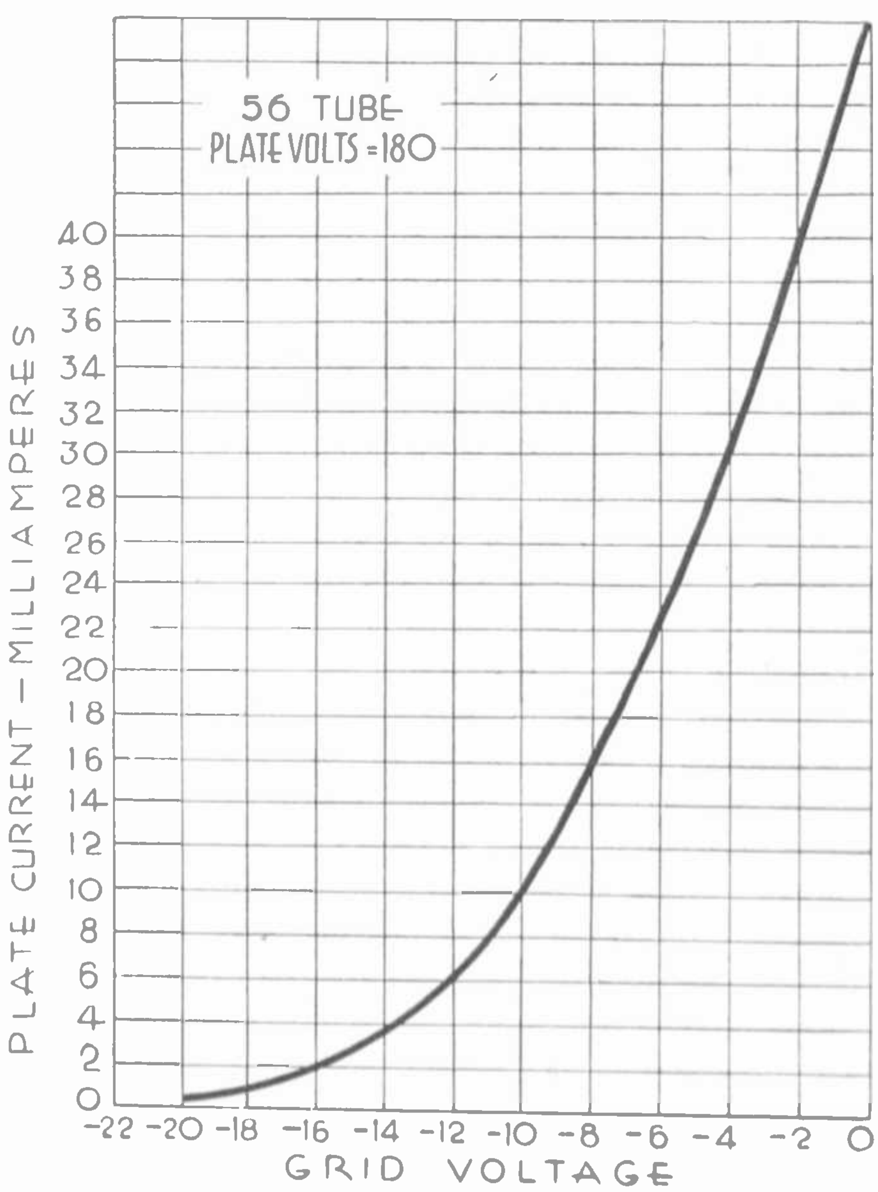


Fig. 29.

17 volts negative the plate current is not decreasing nearly as rapidly for a given voltage drop as it was when nearer the zero point. This graph tells you exactly how the plate current acts as the grid voltage is changed. A graph makes a real picture of changing conditions.

With the help of graphs I will be able to tell you how tubes amplify, how they detect, how they modulate a carrier wave, how they act as oscillators or generators of high frequencies, how they rectify alternating current into direct and how they do all the other wonderful things a tube is capable of doing.

AMPLIFICATION AND VOLUME.

Everyone who has heard anything about radio has heard about "amplification". And of course, everyone has heard talk about "volume". In spite of the fact that many people seem to think these two mean the same thing, they actually are quite different.

Volume is a measure of sound intensity. Loud music has more volume than faint music. Volume affects your ears directly. If a loud speaker can make the window panes rattle, it is delivering lots of volume. If you have to get your ear along side the speaker to hear what's going on, there isn't much volume. Volume is sound.

Amplification is a measure of how many times you multiply the strength of a signal. If a part of your receiver takes in a signal having a strength of 1 volt and then turns out that signal at a strength of 20 volts, the signal has been amplified twenty times. This is real good amplification. Yet the volume may be so small you can hardly hear it.

If you tune in a station 1,500 miles away on an ordinary receiver, you may be amplifying the antenna signal hundreds or thousands of times. Still, the original strength from the antenna may be so exceedingly small that the volume is hardly worth speaking about. On the other hand you may take a signal from a station only three or four miles away, amplify it comparatively little and get enough volume to drive people out of a room.

Amplification is the ability of a receiver or of any radio "amplifier" to multiply the strength of a signal. Volume is the result of the strength of the incoming signal and the amplification applied to it.

HOW A TUBE AMPLIFIES.

Suppose you had an outfit like the one shown in Fig. 30. There is an antenna and ground with a resistor connected between them. The antenna end of this resistor is connected to the grid of a tube and the ground end is connected through a C-battery to the filament of that tube. In the plate circuit of the tube, between the plate and the B-battery, is a second resistor. Let's see what happens.

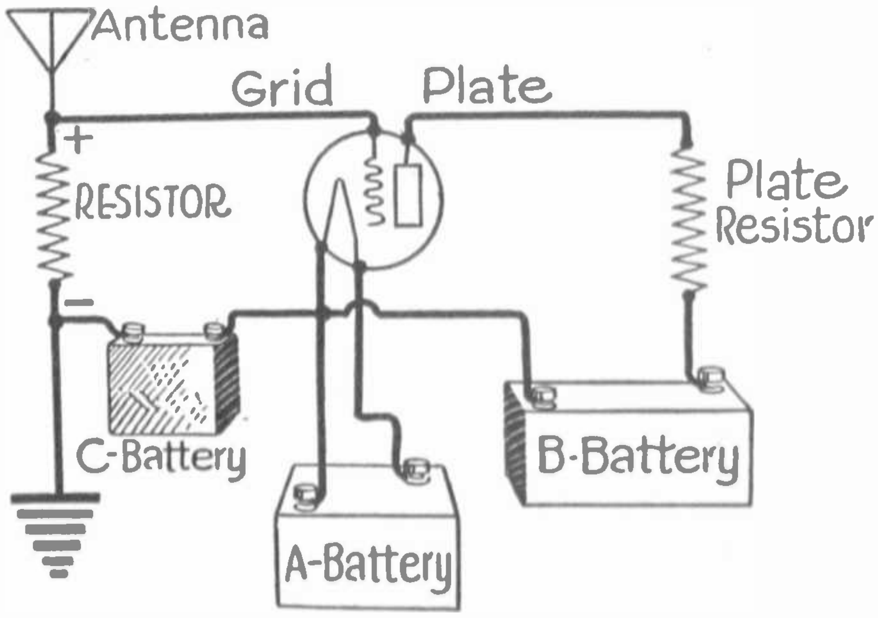


Fig. 30.

As you know, radio signals reaching the antenna cause very small currents to flow between it and ground. Current coming down from the antenna to the grid can't flow through the space in the tube and the tube's filament to the ground connection because the resistance of the space between grid and filament is tremendously great. So the antenna current flows down through the resistor to ground. Here you have current and resistance, consequently, according to Ohm's law, you must also have voltage drop. It is true that flow of the antenna current through the resistor causes a voltage drop and at the instant during which current flows downward, the top of the resistor is at higher voltage than the bottom. The actual potential difference between the two ends of the

resistor might be measured in millionths of a volt, but just to explain the action we will say that the difference is 1½ volts.

This 1½ volts is really applied to the tube's grid circuit and the grid becomes less negative than before. You know that increasing the grid's voltage, or making the grid less negative, allows an increase of plate current. This increase of plate current will have to pass through the resistor in the tube's plate circuit.

We can "plot" the current changes on a graph. In Fig. 31 I have drawn a heavy arrow pointing toward the value of plate current when the antenna voltage is positive. The plate current with the antenna positive is higher than the current when there is no voltage from the antenna. You can compare the graph of Fig. 31 with that of Fig. 29 and see how we use these curves.

In Fig. 32 there is another graph on which the heavy arrow points toward the value of plate current when the antenna voltage is negative. The grid voltage is now brought down below where it stands with no antenna voltage, or with only the C-battery voltage. In Fig. 31 we find 7 mils of plate current due to the antenna action raising the grid voltage. In Fig. 32 we find only 4 mils of plate current because the antenna action has lowered the grid voltage.

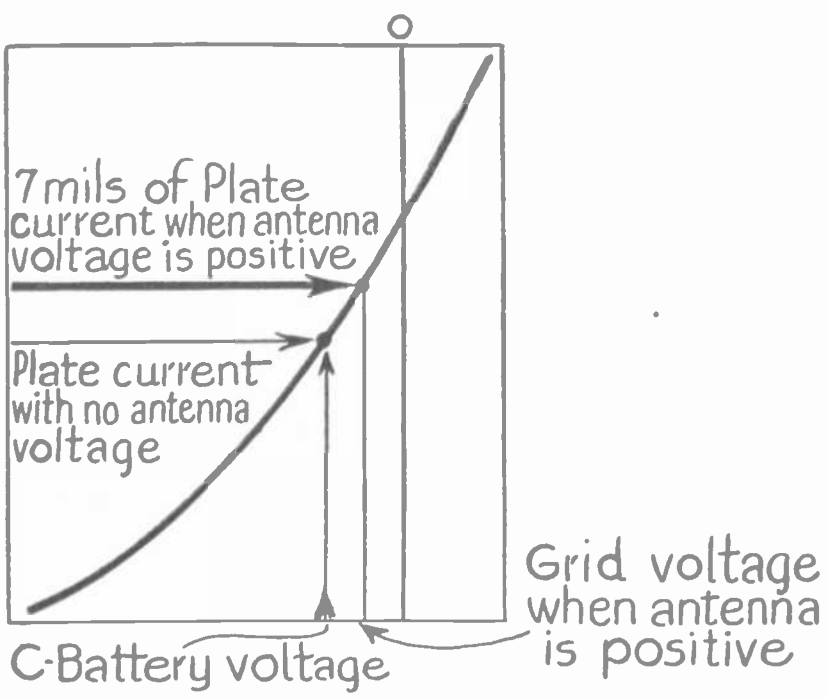


Fig. 31.

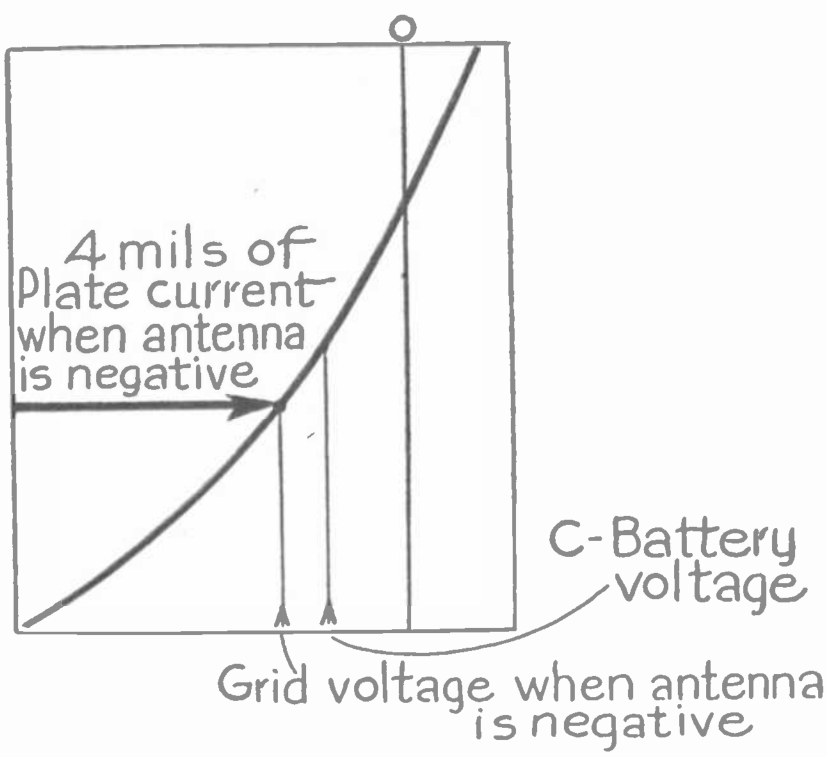


Fig. 32.

Now we'll see what this changing plate current does in the tube's plate circuit. Of course, we have shown only one rise and fall of antenna voltage, but as the signal continues to come in, the rises and falls follow each other rapidly and the plate current rises and falls just as rapidly.

In Fig. 33 we have the plate circuit resistor carrying the 7 mils of current while the antenna voltage is positive. The resistor has a value of 5,000 ohms and the voltage drop across it with 7 mils of current is 35 volts.

In Fig. 34 we have the plate circuit resistor carrying only 4 mils of current while the antenna voltage is negative. This reduced current produces a drop of only 20 volts.

Now we have raised the grid voltage 1½ volts, then droped it 1½ volts, making a total change of 3 volts. In the plate circuit we have first a drop of 35 volts, then a drop of only 20 volts. This means a change of 35 minus 20, or 15 volts in the plate circuit. A 3-volt change on the grid side has produced a 15-volt change on the plate side and we have amplified the grid signal by 5. We have multiplied the 3-volt signal by 5 and have secured 15 volts change in the plate circuit.

The tube and the resistor amplified the voltage to 5 times its original value. The amplification was possible because a comparatively small change in grid voltage pro-

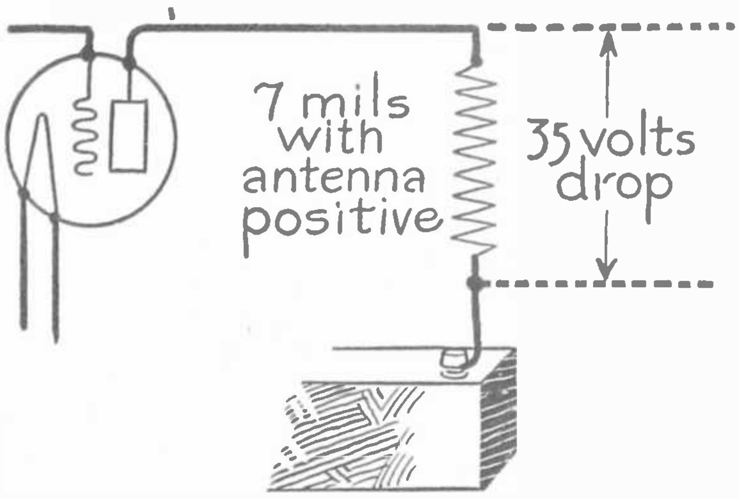


Fig. 33.

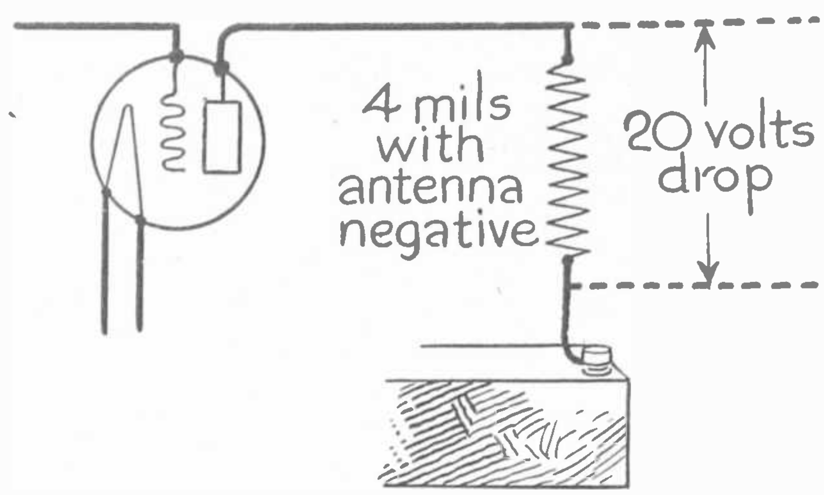


Fig. 34.

duced a large change in plate current. The change of plate current is able to produce changing drops of voltage in the plate circuit.

The actual change of voltage we secured in the plate resistor depended on two things; on the current flowing through it and on the amount of resistance in ohms. Had the current remained the same and had we doubled the resistance, we would have had twice as much voltage drop. Had we halved the resistance, with the same current, we would have secured only half the voltage drop.

You see, the voltage secured in the plate circuit depends a whole lot on the amount of opposition this circuit offers to flow of current through it. In Figs. 30 to 34 we used a resistor to provide opposition to the current. Quite a few radio amplifiers actually do use resistances or resistors to produce voltage drops. But the great majority of amplifiers use coils of one kind and another in place of resistors. The opposition offered by coils is called "reactance" and "impedance".

EXAMINATION QUESTIONS -- #19.

1. When you increase the plate voltage will the plate current increase or decrease?
2. Is an electron positive or negative in polarity?
3. Do electrons flow from the plate to the filament or from the filament to the plate?
4. Does making the grid more negative cause the plate current to increase or decrease?
5. When you say that the grid is negative, with respect to what other part in the tube is it negative?
6. In order that no current may flow in the grid circuit, should the grid be positive or negative?
7. With a negative bias of 6 volts and a 3-volt positive signal potential applied to the grid, what is the actual grid voltage at that instant?
8. In an A.C. heater type tube what is the name of the part from which electrons are emitted?
9. I showed you a graph of the effect of changing grid voltage on the plate current in a "56" tube. Look at that graph and tell me whether there is a greater change in plate current between 2 volts and 3 volts negative or between 9 volts and 10 volts negative.
10. If a 3-volt change in voltage is applied to a tube's grid and a 30 volt potential change appears in the plate circuit what is the amplification?