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HOW GRAPHS ARE USED IN ELECTRONICS

ASSIGNMENT 25B

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The ability to work with graphs will prove very useful in many phases of your electronics work. We have used graphs in some of the preceding assignments, for example, sine waves; but in this assignment, we shall study the use of graphs in more detail.

When there are two sets of facts which are related, the relation between them can often be shown very simply and clearly by means of diagrams, or as these diagrams are usually called, **graphs**. Such graphs are frequently used in business and are very often used in electronics and other technical subjects. Graphs are usually drawn on squared paper or **graph paper**, since the small squares form a very convenient method of locating a particular point on the graph. Two lines at right angles (90 degrees) to each other are used as the axes or reference lines. The horizontal line is called the **"X" axis** and the vertical line is called the **"Y" axis.** This is shown in Figure 1. The point where these two axes cross is called the **origin.**

Values convenient for the problem being considered are assigned to the horizontal and vertical divisions of the X and Y axes. Any point on the X axis to the **right** of the origin is considered to be a **positive** point. Any point on the X axis to the **left** of the origin is **negative** as indicated in Figure 1. Similarly, any point on the Y axis **above** the origin is considered to be **positive**, and any point on the Y axis **below** the origin is considered to be **negative.** In most graphs, points are plotted in relation to the two axes. Then these points are connected by straight lines or curves, forming some sort of a curve which shows **graphically** the relationship that exists between the two sets of facts.

Locating a Point on a Graph

Let us see how we would locate a point on the graph shown in Figure 1. For an example, let us locate a point which represents plus 3 on the X axis and plus 3 on the Y axis. Such a point is shown at A in Figure 1. To locate this point, we count three divisions to the right (plus) on the X axis. Then we count three divisions up from the origin on the Y axis. If a line is drawn from the 3 on the X axis parallel to the Y axis, and a line is drawn from 3 on the Y axis parallel to the X axis as shown by the dotted lines in Figure 1, the point where these two lines intersect will be the location of the point which represents $X = +3$, $Y = +3$.

Now let us locate a point which represents $X = +2$ and $Y = -3$. We have called this point B on the graph in Figure 1. To obtain this point we move 2 divisions to the right on the X axis and draw a line parallel to the Y axis as shown. Then we move 3 divisions down on the Y axis from the origin. We count down in this direction since we are interested in a negative 3 value of Y. At Y equals a —3, we draw a line parallel to the X axis and these two lines intersect at point B as shown in Figure 1.

We have followed this same method to locate several other points on Figure 1. For example, the point C represents X = —2 and Y = —2. Point D is the point which represents X = —1, Y = 2. Apply this same method and find what points E, F, and G represent in Figure 1. Now that we have seen how to locate a point on a graph, let us draw a simple graph locating a number of points and then connect these points by a line as explained above.

Typical Graphs

A business man might have prepared the graph shown in Figure 2. The positive X axis is marked off in 12 equal divisions representing the months of the year. Since there are no negative months of the year, the negative side of the X axis has not been considered. The Y axis has been marked off in the dollar volume of sales. Notice that each division of the Y axis represents $1000. During the month of January the volume of sales was $5000. This point was located by moving out the X axis to January and drawing the dotted lines as indicated. Then another line is drawn from the 5 (representing $5000) on the Y axis. At the point where these two lines cross, as illustrated in Figure 2, the point is located representing the volume of sales for the month of January. In a similar manner the other months sales are located.

Check these values on the graph and see if you understand the location of each point: February sales $4300, March sales $4700, April sales $4900, May sales $3000, June sales $2700, July sales $2000, August sales $2900, September sales $4000, October sales $3900, November sales $5500, and December sales $8800. For any given month, the graph shows the amount of sales. These points are then connected by a line as shown in Figure 2. This information could just as easily be obtained from sales records. When the information is plotted in the form of a graph, however, several other interesting details are clearly shown. The seasonal trends in sales indicate that it might be advisable to develop a new line of merchandise that would sell in the slow months of May, June, July, and August. The large volume of business shown in November and December can be expected each year. The graph warns the business man to order sufficient stocks of goods in early fall to take care of the expected demand.

Graphs, used in electronics work, often contain considerably more information than a simple table of values would give. We have seen in previous assignments that graphs of voltage and current waves were very useful in studying alternating current and voltage. We will also find graphs of the operation of vacuum tubes and transistors to be almost indispensable in the study of those subjects.

Before plotting a graph, it is often convenient to put the material in the form of a chart such as that shown in Figure 3(A). These charts usually consist of two vertical columns. The left column is normally used as the points to be plotted on the X axis and the right column used as the points to be plotted on the Y axis.

To illustrate the use of this method, let us suppose that we wanted to draw a graph showing the relationship of wire sizes in the Browne & Sharpe Gauge and the ohms per 1000 feet of various sizes of wire. By referring to an engineering handbook, we could learn the resistance for 1000 feet of various sizes of wire. A number of these are shown in Figure 3(A). As an example, copper wire of number 4 gauge has a resistance of .25 ohm per 1000 feet, number 7 wire .5 ohm per 1000 feet, number 10 wire 1 ohm per 1000 feet, etc. These values, and other convenient values, are put in the chart as shown in Figure 3(A). Then the graph is drawn as shown in Figure 3(B). Since wire cannot have less than zero ohms resistance, we do not have to consider negative values of resistance. Consequently, the graph is laid off, showing only the positive side of the X axis and the positive side of the Y axis. After making up the table as shown in Figure 3(A) and laying out a convenient set of axes, the various points are plotted as shown in Figure 3(B). For example, number 19 wire has a resistance of approximately 8 ohms for 1000 feet as indicated in the table. To locate this point on the graph, we proceed to the right on the X axis until we reach the line marked number 19. We proceed up the line on the graph paper which crosses the X axis at 19, and locate the point at the intersection of this line and the line which is parallel with the X axis and passes through 8 on the vertical Y axis.

Similarly, we locate the point for the number 16 wire at approximately 4 on the Y axis and so on. After we have located the various points, they are then connected together by a line. Notice that the line which is used to connect these points together does not consist of a group of straight lines between adjacent points. Rather, the line which is drawn between the various points is called the **smooth line.** In drawing the lines between the points, we should attempt to draw the entire line as one smooth curve. Figure 4 emphasizes what is meant by a smooth curve.

In Figure 4, we see four points, point A, B, C, and D. The dotted line shows what results when these points are connected by straight lines. If, on this graph, all the intermediate points between A and B had been plotted, it would be found that the dashed lines would not go through all these points but rather the points would fall on the curved line which is shown as a solid line in Figure 4. To avoid plotting all the intermediate points between A and B, B and C, etc., the graph can be drawn accurately by drawing a smooth curve as illustrated by the solid line between these points. A little practice will enable you to do this with little difficulty.

Again referring back to Figure 3(B), we see that by drawing a smooth curve through the points which we have located on the graph, we will have an accurate picture of the relationship of the resistance of copper wire and the gauge number in the Browne & Sharpe gauge.

In certain cases, the graph will be found to be a straight line. Such a graph is shown in Figure 5(B). For example, suppose we wished to plot a graph of the electrical characteristics of a 50 ohm resistor. That is, we wish to show on a graph the relationship of the voltage drop across this 50 ohm resistor and the current flowing through the 50 ohm resistor. (Actually this graph will be of little value since Ohm's Law itself gives us a good picture of the relationship between the voltage and current for a given resistor.)

Graphing An Ohm's Law Problem

We will use the Ohm's Law formula $E = IR$. Since we are plotting the electrical characteristics of a 50 ohm resistor, R will equal 50 ohms in the formula. Therefore, $E = I \times 50$ or $E = 50I$. E and I are called the **variables** in our equation, so we will use volts as one axis and amperes as the other axis. Before proceeding with our graph, we will prepare a table of values as explained above. All we have to do is to assign different values to I (in the table of values of Figure 5(A), we have chosen values of current of 0 amperes, 1 ampere, 2 amperes, 3 amperes, —1 ampere, and —2 amperes) in our equation $E = 50I$, and for each value of I find the corresponding value of E. We will then record the value of I chosen, and the amount of E which results, in the table of values. For example, if $I = 2$ amperes; $E = 50I = 50 \times 2 = 100$ volts. Likewise, if there is no current flowing, or zero I, the voltage will also be equal to zero since 50 times zero is zero. This is also recorded in our table of values. In a similar manner, we find the voltage when one ampere of current, and three amperes of current, are flowing through this 50 ohm resistor. All these values are recorded in the table in Figure 5(A). If we let $I = -2$ amperes, we will find from solving the algebraic equation that E will be equal to —100 volts [$E = 50I = 50(-2) = -100$]. All this tells us is that the voltage drop in the resistor will be in the opposite direction if we reverse the direction of the current flow.

Now that we have the table values prepared, let us consider our graph. Since we will have negative values of current and voltage, we lay out our graph with the X and Y axes extending on both sides of the origin. In the graph in Figure 5, we used the **horizontal axis** to indicate voltage, and the **vertical axis** to indicate current. We could just as well have used current on the horizontal axis and voltage on the vertical axis. In the table of values in Figure 5(A), we have found six pairs of values of voltage and current, so there will be six points plotted on the graph. These points are plotted as in the previous graph and a line drawn through them. In this case, the line drawn through the points forms a **straight** line. Any equation, whose graph will form a straight line, is called a **linear** equation.

Let us check the graph of Figure 5(B) to see that the location of each point is understood. In the table of values, we find that when the current (I) is 0, the voltage (E) will be 0 also. Thus, our first point on the graph will be at the origin, since this is 0 on the X axis and 0 on the Y axis. The next point in our table of values is $I = 1$, $E = 50$. To locate this point on the graph, we proceed up to the Y axis to the point which represents $Y = +1$ and draw the dotted line shown parallel to the X axis. Then we proceed out the X axis to the point 50 and draw the dotted line shown parallel to the Y axis. The point of intersection (point where the dotted lines cross) is the location of the desired point on the graph. In a similar manner, we locate the points I = 2, E = 100, and I = 3, E = 150. To locate the point I = —1, E = —50, we proceed **down** the Y axis to the point —1, and draw the dotted line parallel to the X axis. Then we proceed out the X axis to the left and locate the point where E = —50, and draw the dotted line parallel to the Y axis. The desired point is located at the intersection of the two dotted lines. In a similar manner, we locate the point I = —2, E = —100.

For practice, draw a set of axes on a sheet of the graph paper which has been supplied to you. Assign values to the vertical and horizontal lines, and plot a graph from the table of values of Figure 5(A). Does your graph look like Figure 5(B)? Is your graph a straight line?

Using a Graph to Learn Facts

After a graph has been properly drawn, many points besides those used to plot the graph may be located on the graph. To illustrate this, refer to Figure 5(B). Suppose we wished to know what the voltage drop would be if the current was 1.5 amperes. To do this we merely find the point on the vertical axis which represents 1.5 (this will be half-way between 1 and 2 on this axis). From this point, which we will label (b), draw a line which is parallel with the X axis as shown in Figure 5(B). At the point where this intersects the line drawn between the various points, another line is drawn which is parallel to the Y axis. The point at which this intersects the X axis, point A, on the graph of Figure 5(B), will indicate the amount of voltage. In this case, the dotted line crosses the X axis half-way between 50 and 100. Thus we find that if there is 1.5 amperes of current flowing through a 50 ohm resistor, there will be a voltage drop of 75 volts across that resistor. (Half-way between 50 volts and 100 volts is 75 volts.)

Let us apply this same method to find the size of wire, in Figure 3(B), which will have a resistance of 5 ohms for 1000 feet. Check this graph carefully and see if you agree that a number 17 wire would have this value of resistance.

Graphs Representing Vacuum Tube Operations

Graphs are used very often in explaining the operation of vacuum tubes. For example, suppose we had a circuit as shown in Figure 6(A). In this case, we have a triode type of vacuum tube connected in a circuit with a 90 volt "B" battery (plate voltage 90 volts) and a grid battery across which is connected a variable resistor so that a variable amount of voltage can be applied between the grid and cathode on the tube. A milliammeter in series with the plate circuit of this tube will indicate the amount of current flowing. From what we have learned of vacuum tubes, we know that as the grid on this vacuum tube is made more negative in respect to the cathode, less plate current will flow and vice versa.

Let us draw a graph showing the relationship between the grid voltage on the vacuum tube in Figure 6(A), and the plate current which flows. First, we would make a table of values as shown in Figure 6(B). This would be done by adjusting the potentiometer in the grid circuit so that the voltmeter would read zero volts, and then reading the plate-current meter. In this case, the plate current is 6 milliamperes. Then the grid potentiometer would be adjusted for a reading of —1 volt, and the plate current is found to be 4 milliamperes. We continue this same process for grid voltages of —3 volts, —4 volts, —5 volts and —6 volts, recording for each the amount of plate current flowing. At —6 volts, we find the plate current has been reduced to zero, or in other words, there is no longer any plate current flowing.

To obtain the plate current which would flow with grid voltages of +1 volt and +2 volts, it would be necessary to reverse the connections to the grid battery. The values of plate current for these two voltages are also shown in the table in Figure 6(B). All of these points are then plotted on the graph in Figure 6(C). Check the location of each point on the graph to make sure that you could draw a similar graph if you were given a table of values similar to that in Figure 6(B). A smooth curve is drawn through these points, and the graph in Figure 6(C) is thus obtained. (This graph is very often called the **characteristic curve** of the tube.) Since the two variable quantities, that is—the two quantities which are varied, are the grid voltage and the plate current, this type curve is often called the **grid-voltage plate-current characteristic curve** of a vacuum tube. It is common practice to use the Y axis as the plate-current axis and the X axis as the grid-voltage axis on this type of curve as shown in Figure 6(C).

As we continue our study of vacuum tubes, we will find such curves are very valuable in determining how a particular tube will operate in an electronics circuit. Notice particularly that this **characteristic curve** is not a straight line. There is one region on this particular curve which is reasonably straight; that is the portion of the curve which lies between the grid-voltage region of —2 volts and zero volts. This is called the straight-line portion of a grid-voltage plate-current characteristic curve. The grid-voltage plate-current characteristic curves for most vacuum tubes will have a shape similar to that shown in Figure 6(C). Different reference points will be used on the axes of different types of vacuum tubes. For example, in some cases the plate current range of a vacuum tube might be from zero to 100 milliamperes, instead of from zero to 7 milliamperes as in this case, and in other tubes the grid voltage might range from a —30 volts to +10 volts.

Through the use of the curve as shown in Figure 6(C), it is possible to estimate the amount of plate current which will flow for almost any value of grid voltage. For example, if the grid voltage on this particular tube were adjusted to negative 1.5 volts, the plate current would be approximately 3 milliamperes. Likewise, we see that a negative .6 of a volt on the grid would produce a plate current of 5 milliamperes. For your own practice, find the amount of plate current which would flow in this circuit if the grid voltage were —2.5 volts, plus .5 volt and plus 1.5 volts. Also, find the amount of grid voltage which would be required to produce a plate current of 5.5 milliamperes.

Other Electronics Graphs

Figure 7(A) shows a graph with which we are now familiar. This is the graph of a sine wave. In this graph the X axis is marked off in time in degrees and the Y axis is marked off in voltage. Since time is a real and positive quantity, the negative part of the X axis is omitted. The table in Figure 7(B) lists the voltage values at intervals of 30 degrees from 0 degrees to 360 degrees. The various points are plotted as shown on the graph in Figure 7(A) and are then joined by a smooth curve. Since we have studied alternating currents in detail, this sine wave graph is familiar to all. but is included to illustrate the fact that graphs are very convenient in studying electronics circuits.

Figure 8(A) shows a simple electrical circuit. This circuit consists of a fixed resistor R_1 of ten ohms in parallel with the variable resistor R_2. Let us draw a graph of the equivalent resistance of this circuit as R_2 is varied. The table of values is shown in Figure 8(B). The formula for finding the equivalent resistance of two resistors is:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_1 = 10 \text{ ohms,}$$

therefore

$$R_T = \frac{10 \times R_2}{10 + R_2}.$$

We have chosen values of R_2 of 2 ohms, 6 ohms, 10 ohms, 14 ohms and 18 ohms. Each of these values is substituted in the equation, and the equation is solved for R_T. This information is shown in the table of values in Figure 8(B). Each of the individual points is plotted as shown in Figure 8(C), and the points are then connected by a smooth curve. This curve illustrates the manner in which the equivalent resistance (R_T) of the parallel resistors varies as R_2 is varied. By referring to this curve, we can closely estimate the value of R_T for the particular value of R_2. For example, if R_2 is 9 ohms, the graph will tell us that R_T will be approximately 4.7 ohms. Likewise, if an equivalent resistance of 6 ohms is desired from the combination, the graph will tell us that R_2 should be adjusted to 15 ohms. Use the graph to determine the value of R_T, when R_2 is 7 ohms, and when it is 12 ohms. Then, use the formula for parallel resistors to check your results and determine the amount of accuracy of the estimated value from the graph shown in Figure 8(C).

An interesting graph will result if we plot the relationship of the power and current in a resistor. We will use the same 50 ohm resistor we had in

Figure 5. A table of values is shown in Figure 9(A) and the graph obtained from these figures is shown in Figure 9(B).

In choosing the values of Current (I) in our table, we used +1, +2, +3, +4, and —1, —2, —3, and —4. The power formula, which we have learned in a preceding assignment, is:

$P = I^2R$.

In this case, R is equal to 50 ohms, therefore $P = I^2 \times 50$ or $50I^2$. If I is equal to +1 ampere, $I^2 = (+1)\ (+1) = 1$, and power $= 50I^2 = 50 \times +1 = 50$. In a similar manner, we can find the amount of power when the current is +2 amperes, +3 amperes, and +4 amperes. If the current is equal to —1 ampere, then $I^2 = (-1)\ (-1) = +1$. Remember that a minus times a minus will give a positive value for an answer. The power, in this case, will be $P = 50 \times 1 = 50$. Thus, we see if I = plus or minus 1 ampere, P = +50 watts. The plus or minus 1 ampere is written ±1. Thus, we will have two points on our graph where the power is equal to 50, one of these will be located at +1 on the X axis or current axis in this case, and the other point will be at —1 on the current axis in this case. This is shown in Figure 9(B). Similarly, there are two points on the graph where the power is 200 watts, when I = —2 amperes, and I = +2 amperes. We also locate two points where the power is 450 watts and where the power is 800 watts. The graph indicates the fact that the power dissipated in a resistor will be the same regardless of the direction of current flow through the resistor.

It is often desirable to plot two or more graphs on one set of axes. For example, a television serviceman starting out his first year in a part-time service business might plot two items on the same graph. In Figure 10, the income or revenue has been shown by the solid line of the graph. The operating costs of the business have also been plotted and are shown by the dotted line. From January through March, the cost of operating the business exceeded the revenue. April was the **critical** month, when revenue reached operating costs. From then on the business was on its feet and operating at a profit. The point of intersection of the two lines shows that in the month of **April** the revenue and costs were both $400.

Families of Curves

In some cases, when several graphs are drawn on the same set of axes, the results are called a **family of curves**. Families of curves are often used when studying the characteristics of transistors and vacuum tubes. For example, refer to the family of curves given for a 6CW4 vacuum tube in your vacuum-tube manual. In this family of curves, the X axis is marked off in plate voltage and the Y axis is marked off in plate current. Before considering the family of curves, let us look at just one curve and learn to understand it, then we will consider the entire family of curves. For example, let us determine how the curve which is marked $E_c = 0$ is obtained. Figure 11(A) illustrates the circuit arrangement which would be used to obtain the data for such a curve. The $E_c = 0$ which is referred to in the graph on the family of curves of the 6CW4 tube means the grid voltage. This would be read by the voltmeter connected between the grid and the cathode in Figure 11(A). The plate voltage would be measured by the voltmeter connected in the plate circuit between the plate and the cathode, and the plate current would be read by the milliammeter in series with the plate circuit. The plate voltage can be adjusted by adjusting the potentiometer in the plate circuit.

To obtain the data for the curve under discussion, the grid voltage would be adjusted for a reading of 0 on the grid voltmeter. The plate voltage is then adjusted in steps of 20 volts, and the plate current read for each step. As an example, the plate voltage is set at 0 and the plate current is found to be 0. When the plate voltage is set at 20 volts the plate current is found to be 3 milliamperes. With a plate voltage of 40 volts the plate current is 7 milliamperes, etc. All of this information is placed in a table of values as shown in Figure 11(B). When all of these points given in Figure 11(B) are plotted on the set of axes and these points are connected by a smooth curve, the curve labelled $E_c = 0$ will be obtained. This curve shows how the plate current in a vacuum tube varies in respect to the plate voltage changes when the grid voltage is 0 volts. The actual operation of the vacuum-tube circuit will be taken up in greater detail in another assignment, but in this case, we want to study the **graphs** which are obtained in such cases.

The curve next to the one which we have been discussing is labelled —0.5. This means the grid voltage E_c is adjusted to 0.5, or ½, volt. Then the plate voltage is adjusted in steps of 20 volts as previously outlined, and the amount of plate current which flows is recorded in a table of values. Then, when these points are plotted and connected by a smooth curve, the curve shown in the tube manual labelled —0.5 will result. Likewise, the curve labelled —1 results when grid voltage is adjusted to a —1 volt and the plate voltage is varied, and the amount of plate current which flows is recorded in a table of values. In a similar manner, curves for —1.5, —2, —2.5, —3, etc. grid volts are obtained. We shall see later that these graphs, or **characteristic curves** as they are commonly called when dealing with vacuum tubes, are very valuable in the full understanding of vacuum tubes.

Let us look at the characteristic curves of a number of different types of vacuum tubes, and see how the graphs compare. For example, look at the family of curves given for the 6DE7 tube. Notice that the general look of these curves is similar to that of the 6CW4 tube which we have been discussing. Now look at the curves for the 6DQ5 tube. Notice that these curves look entirely different from these of the 6CW4 tube. We shall see, when we study vacuum tubes, that this tube will operate in a different manner also. For the type of characteristic curve which has a still different appearance, look at the family of curves shown for the 6L6-GC tube. Applying the same logic as before, we can expect this tube to operate differently also. If you will look through your vacuum-tube manual, you will find this to be true. In the majority of the family of curves given, if the tube in question is a triode, such as the 6CW4, the family of curves will have an appearance **similar** to that for the 6CW4. Also, if the tube in question is a pentode tube, a curve similar to that for the 6AU6 will be found. Beam-power tubes will be found to have curves similar to that for the 6L6-GC, or ranging between this curve and the one shown for the 6DQ5 tube.

Slope

Let us plot the graph of several resistors on the same set of axes. We will plot each of these, as was done in Figure 5 for the 50 ohm resistor. Figure 12 shows the graphs for three resistors. The line ending at (A) represents the graph of a 10,000 ohm resistor. The line ending at (B) shows a 1000 ohm resistor, and the line ending at (C) portrays a 100 ohm resistor. Make up tables of values for each of these resistors, and check to see if these lines are drawn properly on the graph shown in Figure 12. On any one of these, we can determine the current through the resistor shown at any voltage, by the method we previously used. Notice particularly, that the lines are **inclined** a different amount. The line representing R = 10,000 ohms is almost horizontal. The line representing R = 100 ohms is almost vertical. This brings us to a property of graphs called, appropriately enough, **slope.** The inclination or **slope** of these three graphs differ each from the other. Let us find a simple way to measure the slope of a graph.

Slope is defined as the change in Y for each unit change in X. That is, if we change a quantity measured along the X axis one unit, the change in the quantity measured along the Y axis is the slope of the line. In Figure 12, the line representing R = 100 ohms has a slope of ten because as we change the value of X from 0 to 1, the value of Y changes from 0 to 10. The line representing R = 1000 ohms has a slope of 1. This is because as we change from 0 to 1 on the X axis, the change is also from 0 to 1 on the Y axis. Notice also that we could determine the slope of the line R = 1000 ohms at some other point. For example, we could determine the slope when we change the value of X from 3 to 4. This would be a change of 1 (4—3 is 1); the value of Y also changes from 3 to 4 or 1 unit. Thus, we see that we find the slope of this straight line to be 1, no matter where it is measured. In a similar manner, we can determine the slope of the line R = 10,000 ohms. When we changed the value of X from 0 to 10, the value of Y changes from 0 to 1, a change of 1. Thus, we find the slope of this line to be .1. All **straight** lines have a constant slope. That is, any straight line has the same slope over its entire length regardless of the point at which the slope is measured.

The slope of a curved line is not constant. In other words, the slope is not the same at different points on the curve. Figure 13 illustrates a graph of a curved line similar to the one shown in Figure 6. The slope of this curve from 0 to A is about the same as the slope of the 10,000 ohm line in Figure 12. We have shown that this line has a slope of .1. Thus, we could say that from 0 to A the slope of the curve is a small value. From B to C on the curve in Figure 13, the slope is similar to the slope of the R = 100 ohm line in Figure 12. This line had a slope of 10 in Figure 12; so we could say that in Figure 13, from B to C, the slope is of a high value. It is apparent that, from B to C, the value along the Y axis changes greatly for a small change in the value along the X axis. By definition of slope, this means that the slope is high. Over the portion of the curve from C to D, the slope is similar to that of the R = 1000 ohms graph shown in Figure 12. We found this line to have a slope of 1. Thus, we see that the slope of a curved line is different at different points on the line.

Refer again to the family of curves given for the type 6CW4 tube in your tube manual. Notice that at values above approximately 4 milliamperes, each of these curves is very close to a straight line. At values of plate current between 0 and 4 milliamperes, each of these graphs has quite a bit of curvature,or, to state this in another way, the slope is not constant at currents below 4 milliamperes of plate current. In our study of vacuum tubes, we shall find that it is usually desirable to operate the tube over the substantially straight portion of this family of curves, since operation of the tube over the range of the graphs where the curvature occurred, that is, below 4 milliamperes, will result in the vacuum tube producing what is called distortion. That is, the signal which is obtained from the output of the vacuum-tube amplifier circuit will not be an amplified version of the input signal.

Refer to the family of curves given for the 6L6-GC tube and it will be seen, that at plate voltages below approximately 60 volts, there is a point where a sudden change occurs in these curves. If this type tube were to be operated over this portion of its curve, a serious amount of distortion would result. For this reason, the plate voltage on this tube is always operated in excess of 100 volts.

It is understood that the amount of vacuum-tube theory which has been studied up to this time, is not sufficient to give a clear understanding of the statements which have been made in this assignment concerning vacuum tubes. The purpose of this assignment is to show the use of the **graphs**. If the graphs themselves are understood, it will be a much simpler matter to understand the operation of the vacuum tubes when we consider this subject in greater detail in a future assignment.

To familiarize yourself with the use of these graphs, let us study some of the families of curves in your tube manual. Refer to the family of curves for the 6DE7. Look at the curve labelled grid volts $E_c = 0$. Let us estimate from this curve what the plate current would be if the plate voltage were 100 volts. If we trace up the vertical line from 100 volts, we will find it crosses the curve ($E_c = 0$) at a point which is approximately 13 milliamperes. Check this thoroughly to make sure that you understand this statement. Also, we could find that a plate potential of 150 volts would produce a plate current slightly in excess of 21.5 milliamperes. We could estimate this to be 21.7 milliamperes. In a similar manner, we could find that 50 volts of plate voltage would produce a plate current of approximately 5 milliamperes.

Now let us look at another curve—for example, the curve $E_c = -8$. When we consider this curve, we find that a plate voltage of 100 produces no plate current. The plate voltage of 150 volts produces approximately 1.5 milliampere of plate current, 200 volts approximately 6.2 milliamperes of plate current, and 250 volts produces approximately 13.5 milliamperes of plate current. Apply this same method to the curve E_c = —2 and find the plate current which would flow at 100 volts, 150 volts, and 175 volts.

Apply this same method for the family of curves given in your tube manual for the 6BA6 tube. What plate current would flow if the voltage curve for grid number 1 ($E_{c1} = 0$) is used, and the plate voltage is 10 volts, 25 volts, 50 volts, and 60 volts? Use the curve E_{c1} = —2.0 volts and find the plate current which would flow for these same plate voltages. For your own familiarization with these families of curves, look up several other families of curves in your tube manual and find the plate currents which would flow for various values of plate voltage on the individual curves.

Summary

In this assignment, we have learned a number of things about graphs. We have learned how to set up a graph—that is, how to draw the X and Y axes and how to locate points on a graph. We have learned how to connect the individual points with a **smooth curve** and form a graph from individual points. We have also seen and discussed a number of uses for graphs. As we progress through our electronics studies, we will find many more uses for graphs. We have seen how to deal with a graph containing many individual graphs such as a family of curves used for vacuum tubes. We have learned how to draw the graph of an equation by substituting values in the equation and preparing a table of values. We have also learned how to determine the slope of a line in a graph.

For your own practice, draw the graphs below on the graph paper provided. Do this work as neatly and accurately as possible to obtain the greatest benefit from these exercises.

Graph number 1. Draw a graph of the circuit shown in Figure 14. Use R_T, the equivalent resistance of R_1 and R_2, as the Y axis and R_2 as the X axis. The formula is given in Figure 14 and the table of values is started for you. Complete the table of values, and then draw the graph of this table of values.

Graph number 2. Draw a graph showing the voltage and current relationship of a 1000 ohm resistor. This graph will be somewhat similar to that of Figure 5. Use voltage as the X axis and current in milliamperes as the Y axis.

Graph number 3. Draw a graph using the table of values shown in Figure 15. Plot time in degrees on the X axis and current in amperes on the Y axis.

Graph number 4. Mark the axes of a graph as they are marked on the family of curves for the 6CW4 tube in your tube manual. That is, mark plate milliamperes from 0 to 35 on the Y axis and plate voltage from 0 to 280 on the X axis. Do not trace in the individual graphs shown in the family of curves. Instead, draw a graph from the table of values given in Figure 16.

Graph number 5. On the same set of axes as used for graph number 4, draw the curve from the table of values given in Figure 17. Label the curve obtained for graph number 4 ($E_c = -1$) and the curve obtained in this graph ($E_c = -2$).

After performing the exercises outlined above, you should have a very good working knowledge of graphs. This will be found to be of a great deal of value in the study of transistors, vacuum tubes and electronics circuits, which will be encountered in future assignments. If there is any doubt whatever in your mind concerning the drawing of graphs, you are advised to make out a number of tables of values of your own, and then graph these points. An interesting graph that you might make is to estimate your weight for your different ages, and then draw a graph of these values. Another graph which might prove interesting is to draw a graph of your salary for the number of years which you have been working. You can probably think of many things you can graph: the amount of gas you use in your car and the miles traveled each month; the temperature each hour on the hour, for the last 24 hours (you can probably get this information from the newspaper); the reactance of a 1 henry choke at frequencies from 30 hertz to 3000 hertz; etc. You might find it very interesting to plot the reactance of a 10 μF capacitor on the same graph as the 1 henry choke.

The more graphs you draw the easier it will become and the more meaningful graphs will be to you.

"How to Pronounce . . ."

(Note: the accent falls on the part shown in CAPITAL letters.)

axis (singular)	AK-sis
axes (plural)	AK-sez
graph	GRAFF

TEST QUESTIONS

Be sure to number your Answer Sheet Assignment 25B.

Place your Name and Associate Number on **every** Answer Sheet.

Submit your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

The graphs requested on several of the questions in this assignment should be drawn on the graph paper which has been provided. The graphs should be drawn neatly and legibly but need not be large.

1. Is the horizontal axis of a graph the **X axis** or the **Y axis?**
2. Are negative values on the vertical axis plotted above the origin or below the origin?
3. Draw a graph of the circuit shown in Figure 14, using the following values for R_2: 0, 1, 3, 5, 7, and 9.
4. Make a table of values and draw a graph for a 5000 ohm resistor. Plot voltage on the horizontal axis and current in **milliamperes** on the vertical axis. (Note: Use the formula $I = \frac{E}{R} = \frac{E}{5000}$)
5. Draw the graph from the table of values shown in Figure 15.
6. Refer to the family of curves given for the 6DV4 tube in your tube manual. Using the curve $E_c = -0.5$, what plate current will flow when the plate voltage is 60 volts; when the plate voltage is 40 volts; when the plate voltage is 50 volts?
7. Using the same family of curves as in Question 6 and using the curve $E_c = -2$ volts, what plate voltage will be required to produce a plate current of 8 milliamperes?
8. In Figure 18, what is the slope of the graph from 0 to A?
9. Use the graph of Figure 6(C) to determine the approximate plate current when the grid bias voltage is —2.5 volts.
10. In the graph shown in Figure 7, approximately what is the voltage at 45 degrees, and at 195 degrees?

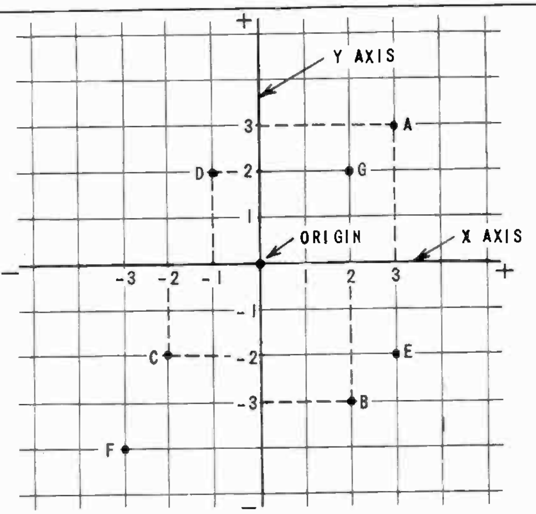


FIGURE 1

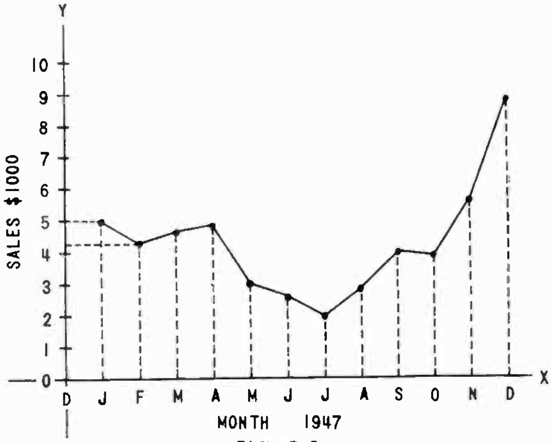


FIGURE 2

WIRE SIZE, B & S GAUGE	OHMS PER 1000 FEET
#4	.25
#7	.50
#10	1.00
#13	2.00
#16	4.01
#19	8.04

(A)

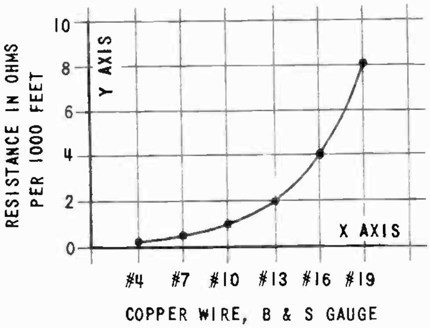


FIGURE 3 (B)

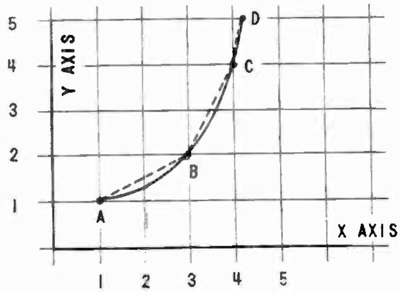


FIGURE 4

TABLE OF VALUES

E	I
0	0
50	1
100	2
150	3
- 50	- 1
-100	- 2

E = IR
E = I50 or 50I

(A)

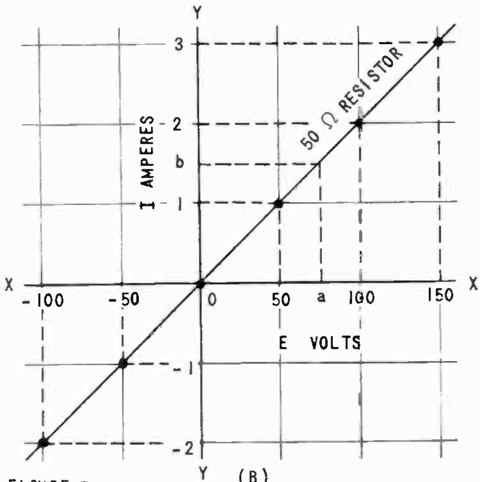
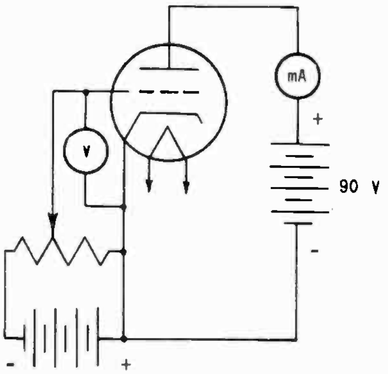


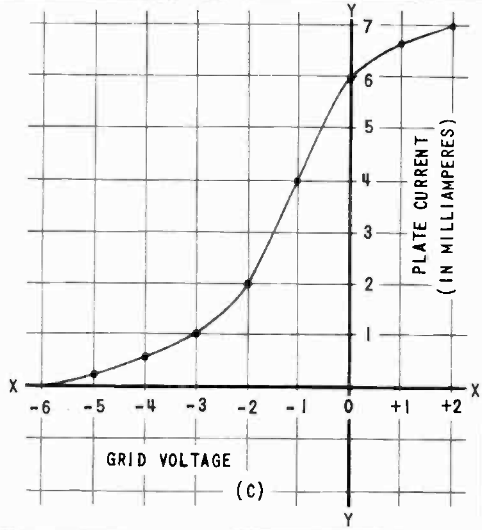
FIGURE 5 (B)



(A)

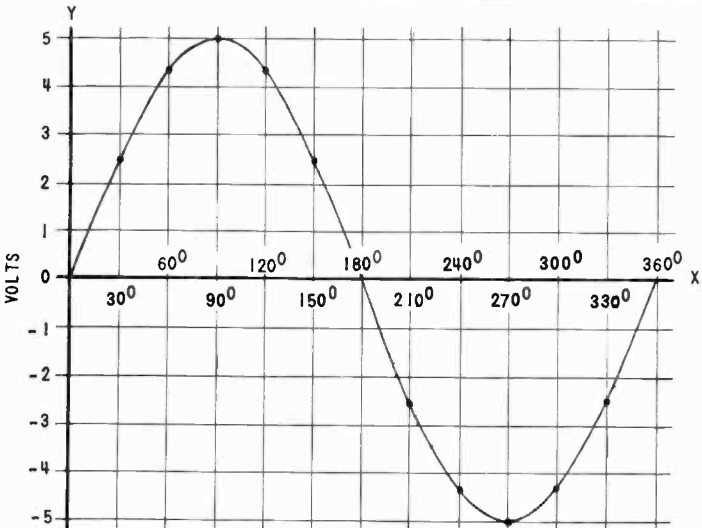
GRID VOLTAGE	PLATE CURRENT (mA)
+2	7
+1	6.6
0	6
-1	4
-2	2
-3	1
-4	.6
-5	.2
-6	0

(B)



(C)

FIGURE 6



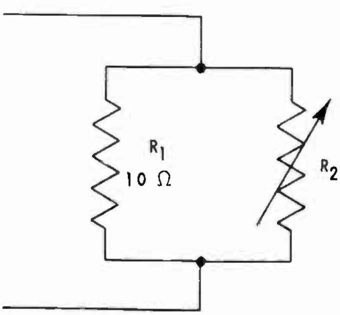
(A)

TIME IN DEGREES	VOLTAGE
0°	0
30°	2.5
60°	4.3
90°	5
120°	4.3
150°	2.5
180°	0
210°	-2.5
240°	-4.3
270°	-5
300°	-4.3
330°	-2.5
360°	0

(B)

FIGURE 7

CIRCUIT



(A)

TABLE OF VALUES

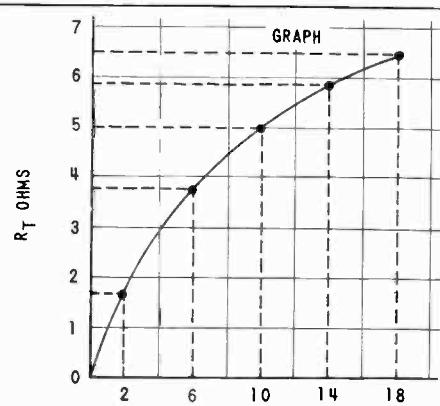
$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_T = \frac{10R_2}{10 + R_2}$$

R_2	R_T
2	1.7
6	3.8
10	5
14	5.9
18	6.4

(B)

FIGURE 8



(C) R_2 OHMS

$P = I^2R$

$P = I^2 \times 50$ OR $50I^2$

I	P
0	0
±1	50
±2	200
±3	450
±4	800

(A)

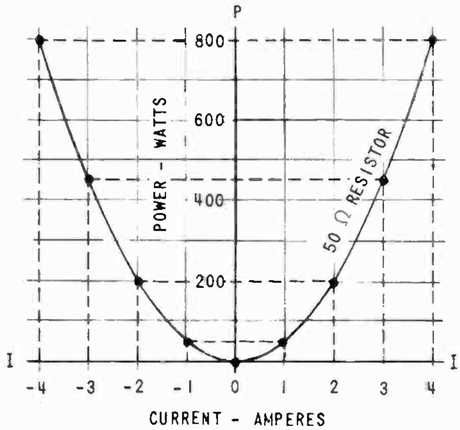


FIGURE 9 (B)

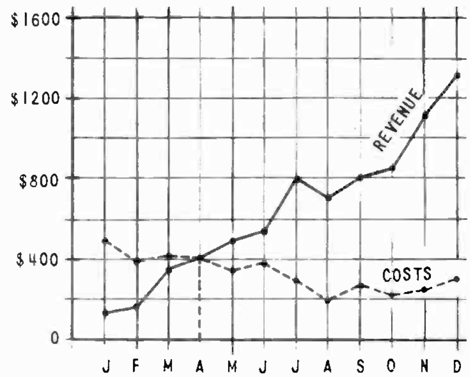
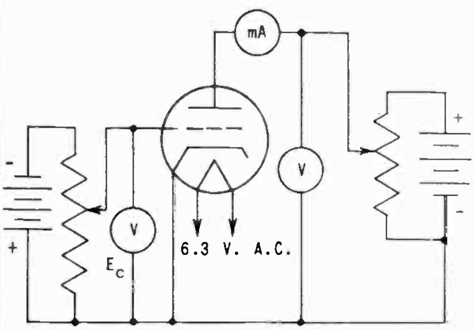


FIGURE 10



(A)

6CW4 TUBE $E_C = 0$

PLATE VOLTAGE	PLATE CURRENT
0	0
20	3 mA
40	7 mA
60	12 mA
80	17 mA
100	22 mA
120	27 mA
140	33 mA

(B)

FIGURE 11

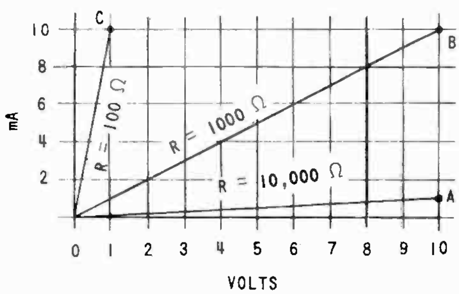


FIGURE 12

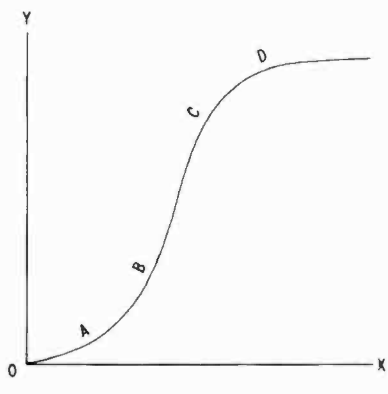
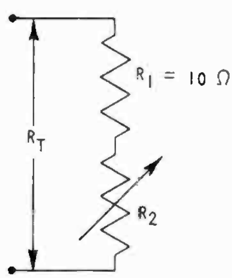


FIGURE 13



$R_T = R_1 + R_2$

$R_T = 10 + R_2$

R_2	R_T
0	10
2	12
4	14
6	16
8	18
10	20

FIGURE 14

TIME IN DEGREES	CURRENT IN AMPERES
0	0
30	5
60	8.6
90	10
120	8.6
150	5
180	0
210	-5
240	-8.6
270	-10
300	-8.6
330	-5
360	0

FIGURE 15

PLATE VOLTS	PLATE CURRENT (mA)
0	0
20	0
40	0
60	2
80	3.5
100	5
120	8
140	12.5
160	17

FIGURE 16

PLATE VOLTS	PLATE CURRENT (mA)
80	0
100	1
120	2
140	4
160	7
180	10
200	18

FIGURE 17

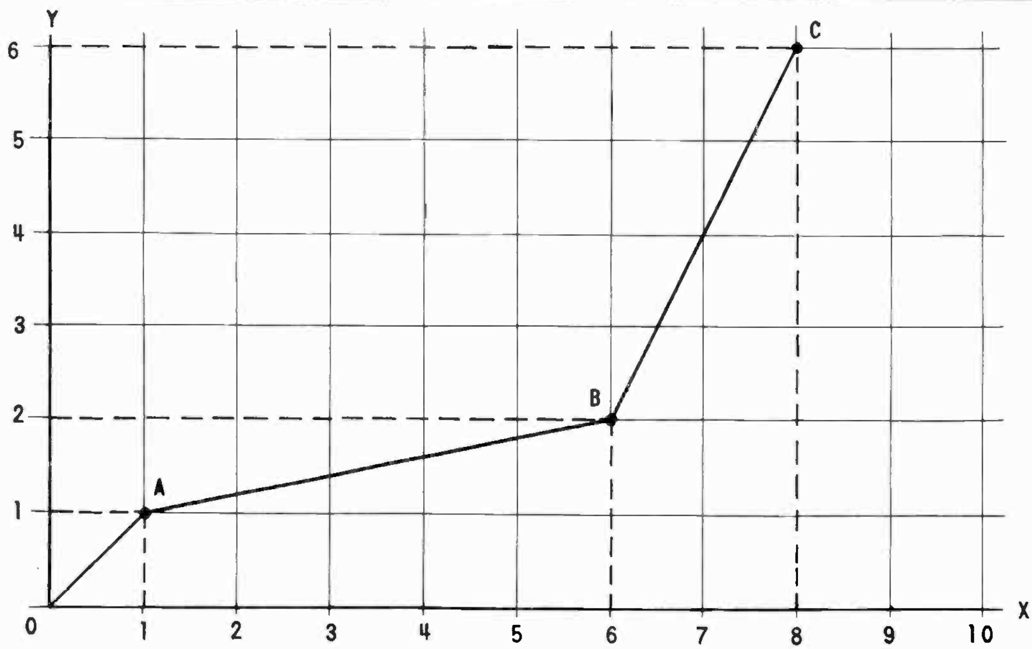


FIGURE 18

THIS IS THE WAY SOME OF THE GRAPHS WOULD LOOK ON YOUR GRAPH PAPER.