1-1958

Physics, Chapter 35: Electronics

Henry Semat
City College of New York

Robert Katz
University of Nebraska-Lincoln, rkatz2@unl.edu

Semat, Henry and Katz, Robert, "*Physics*, Chapter 35: Electronics" (1958). *Robert Katz Publications*. 183.
https://digitalcommons.unl.edu/physicskatz/183

35

Electronics

35-1 Thermionic Emission

The electrons of an atom occupy certain energy levels when the atom is far from other atoms. When a large number of atoms are assembled to form a conducting metallic solid, the energy levels of the valence electrons are displaced in position to form a *conduction band,* as discussed in Section 28-4. The valence electrons occupy energy levels within the conduction band and are relatively free to drift from atom to atom within the metal. In accordance with a fundamental physical principle, known as the *Pauli exclusion principle,* only 1 electron may occupy a particular energy level. The conduction electrons are not all in the state of lowest energy, for only 1 electron can occupy that level. The conduction electrons tend to fill the bottom region of the conduction band. The number of electrons to be found in a

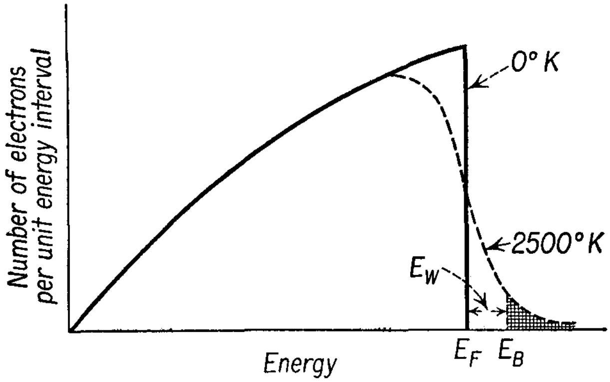

Fig. 35-1 The Fermi-Dirac distribution of electron energies in tungsten at 0°K and 2500°K, showing the position of the Fermi level E_F, the binding energy E_B, and the work function E_W (not to scale). Electrons in the shaded area are thermally emitted at 2500°K if they are traveling toward the surface with sufficient energy.

small energy interval centered about a particular energy follows a distribution known as the *Fermi-Dirac* distribution, shown in Figure 35-1. At the absolute zero of temperature, the number of electrons in a given energy interval increases with increasing energy, as shown in the figure. The maximum energy of any conduction electron in the metal is known as the *Fermi* energy E_F. At the absolute zero all energy levels below the Fermi energy are occupied by electrons, and no electron has an energy above the Fermi energy. The particular value of the Fermi energy varies from metal to metal but depends only upon the number of conduction electrons per unit volume of metal.

Another parameter of great interest is the *binding energy*, the energy required to remove an electron from the lowest energy state within the conduction band to a point infinitely distant from the metal. Since electrons normally do not leave the metal, it is apparent that the binding energy E_B is greater than the Fermi energy E_F. The difference between these two energies is called the work function E_W. Thus

$$E_B - E_F = E_W.$$

If an electron at the Fermi level is to be emitted from the body of the metal at the absolute zero, it must be given a quantity of energy E_W. This may be done in a number of ways. When the surface of the metal is struck by a rapidly moving particle, such as a proton or an electron, the kinetic energy of the moving particle is absorbed by the metal and may be given up to some of the electrons in the metal. These electrons are then liberated from the metal by a process called *secondary emission*, which is of great importance in modern *photomultiplier tubes.* A second way for an electron to acquire sufficient energy to be removed from the metal is by the absorption of the energy of a quantum of light; this process is known as *photoelectric emission.*

When the metal is heated to a high temperature, the distribution of electrons within the metal is altered. The energy distribution of electrons in metallic tungsten at 2500°K is shown in dotted lines in Figure 35-1. Those electrons having energies above E_B, shown in the shaded area of the curve, have sufficient energy to escape from the body of the metal and are said to be *thermally emitted.* The fraction of the total number of conduction electrons having sufficient energy to be emitted at a particular temperature depends upon the position of the binding energy E_B with respect to the Fermi energy E_F, hence upon the value of the work function E_W. We must therefore expect the thermionic emission from different metals at a given temperature to vary from metal to metal, according to the differences in work function. From the shape of the distribution curve, we must also expect the thermionic emission to increase rather rapidly with temperature.

The thermionic emission of electrons from a heated filament was discovered by Thomas A. Edison in 1883; it forms the basis of the modern vacuum tube. In such tubes the electron emitter is the negative electrode, or cathode. Because of its high melting point, tungsten is often used for the filaments of tubes which are operated at high cathode temperatures. It is possible to apply low work-function materials to metallic filaments so that these materials act as the source of electrons and the filaments can be operated at lower temperatures for the same emission. In the modern vacuum tube the cathode is often a separate structure surrounding a heater, in order to separate the problem of providing heat from the main function of the cathode as a source of electrons.

35-2 The Diode Rectifier

A thermionic diode is a two-element vacuum tube, in which one element consists of a filament or heated *cathode* which serves as a source of electrons, and the other element, called the *plate*, serves as a collector of electrons. Since the diode is asymmetric in construction, it is also asymmetric in its electrical properties. Electrons can flow in only one direction, from filament to plate.

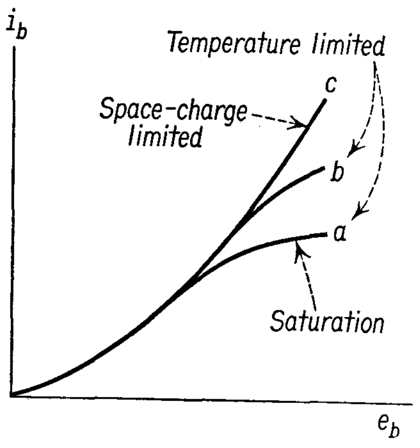

Fig. 35-2 Static characteristics of a typical diode. The filament temperature is increasing from a to c.

When a potential difference is applied between the cathode and plate of the diode, the current through the tube as a function of applied voltage has the form shown in Figure 35-2. The electrons which are emitted from the filament form a space-charge cloud around the filament. When a low positive voltage is applied to the plate, some of the electrons of the space-charge cloud are attracted to the plate; the current is determined by the characteristics of the space-charge cloud. As the plate voltage is increased, more and more of the space charge flows toward the plate, until the current reaches a value appropriate to the cathode emission. The current is then *saturated,* or *temperature limited.* When the temperature of the filament is raised, the current at saturation is greater than previously, as shown in the figure.

Since there is only one direction in which current will flow in a diode, this tube may be used as a rectifier. It is often convenient to think of the diode as a switch which is closed to permit current to flow when the plate is made positive, with respect to the cathode, and which is opened to stop the flow of current when the plate is made negative.

The basic circuit of a *half-wave* rectifier is shown in Figure 35-3(a). An alternating emf ε is generally supplied by a transformer connected to the a-c line. The transformer is connected to a series combination of the diode and a load, shown here as a resistor R_l. The cathode is shown on the diagram as externally heated. For simplicity, the heater filament and the filament transformer have been omitted. The potential difference between cathode and plate ε_b is equal to the emf of the transformer secondary minus the iR drop in the load resistor. Thus

$$\varepsilon_b = \varepsilon - i_b R_l, \tag{35-1}$$

so that the voltage across the load is given by the difference $\varepsilon - \varepsilon_b$.

We may display the meaning of Equation (35-1) graphically by construction of a *dynamic characteristic* curve of the diode, from its *static characteristic*, by means of the concept of a *load line.* The static characteristic of a tube is the plot of current through the tube as a function of plate voltage, under a particular set of conditions, such as a fixed cathode temperature, as shown in Figure 35-2. The dynamic characteristic of the tube in a particular circuit is a plot of the current through the tube i_b plotted as a function of the emf applied to the circuit ε, when a particular load resistor R_l is used.

One relation between the variables ε, ε_b, and i_b is expressed by Equation (35-1). A second relation between two of these variables is known only as a graph, that is, the static characteristic, which expresses i_b as a function of ε_b. These two functional relationships may be solved simultaneously at specific values of ε for ε_b and i_b, so that we can express i_b as a function of ε.

Let us rewrite Equation (35-1) in the form

$$i_b = -\frac{\varepsilon_b}{R_l} + \frac{\varepsilon}{R_l}. \tag{35-2}$$

On a graph in which i_b is the ordinate and ε_b is the abscissa, as in Figure 35-3(b), this is the equation of a straight line of slope $-1/R_l$ and intercept ε/R_l, from the standard slope-intercept form of the equation of a straight line

$$y = mx + b.$$

Equation (35-2) is the equation of the *load line,* which may be most simply drawn as connecting the points of coordinates $(0, \varepsilon/R_l)$ and $(\varepsilon, 0)$, as shown in Figure 35-3(b).

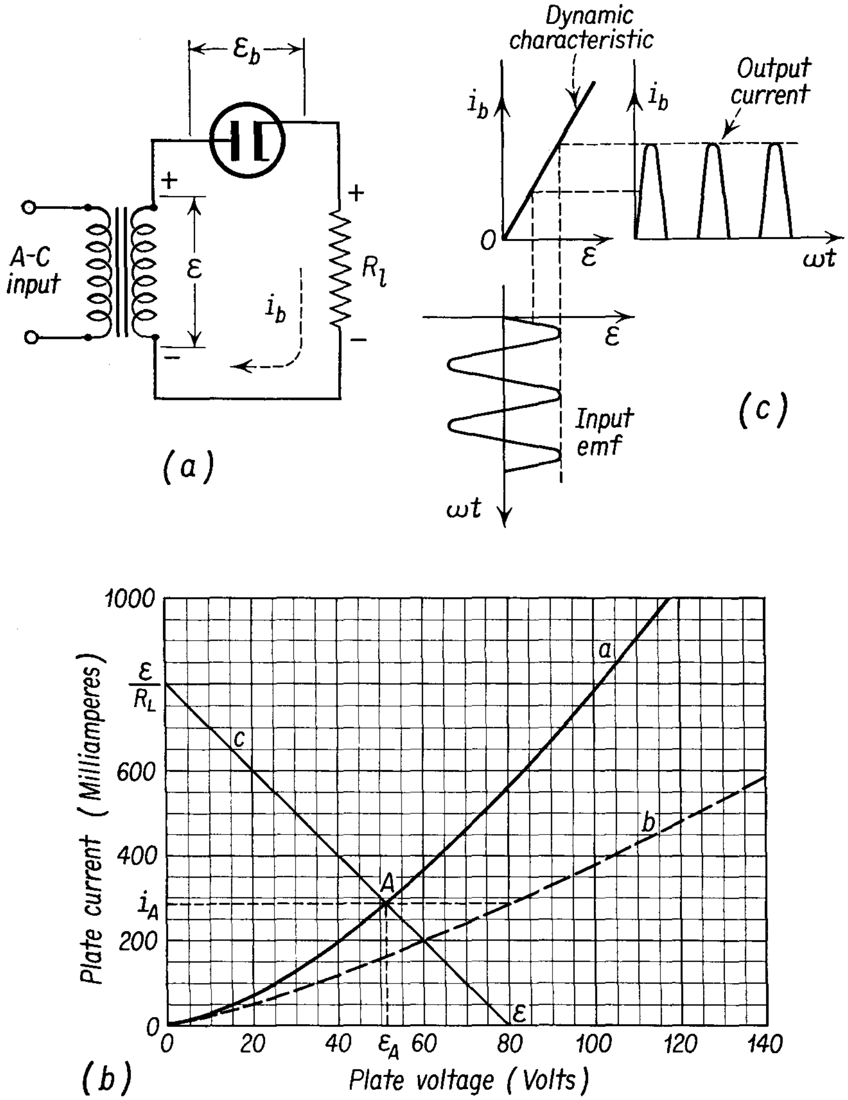

Fig. 35-3 (a) Schematic circuit of a half-wave rectifier. (b) Characteristics of a 5U4–GB diode. Solid line (a) is the static characteristic; dashed line (b) is the dynamic characteristic with 100-ohm load; load line (c) for 100-ohm load resistor drawn for $\mathscr{E} = 80$ volts. When an emf $\mathscr{E}$ is applied to the series circuit of diode and load resistor, the voltage $\mathscr{E}_A$ appears across the tube, and the current i_A flows in the circuit. (Graph courtesy of General Electric Company.) (c) Output current wave form obtained from input voltage wave form from the dynamic characteristic of the diode used in the half-wave rectifier circuit.

The point of intersection of the load line and the static characteristic of the tube represents the solution of the two simultaneous functional relationships for the circuit. For a particular value of the applied emf ε, the intersection of the two curves is at point A, and the current through the tube is i_A. Repeating this operation by displacing the load line parallel to itself for different values of the applied emf ε, we may find the values of ε_b and i_b appropriate to each value of ε.

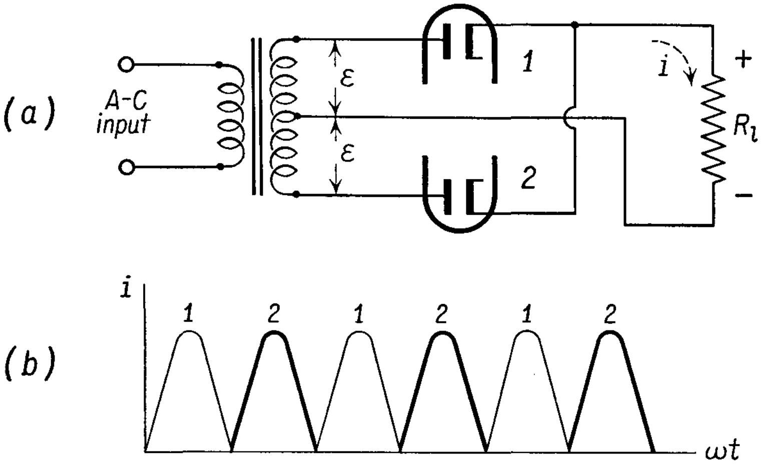

Fig. 35-4 (a) Full-wave rectifier circuit. (b) Current wave form from full-wave rectifier is made up of contributions from the half-wave rectifiers of tubes 1 and 2 which operate on alternate half cycles.

If the applied emf is a sinusoidal function of time, we may imagine time axes to be superimposed upon the dynamic characteristic curve, as shown in Figure 35-3(c), and thus find the wave form of the output current as a function of time for the half-wave rectifier.

When two diodes are so connected that they are conducting during alternate half cycles and yet permit current through the load resistor in a single direction, they constitute a full-wave rectifier. A circuit diagram and wave form resulting from such a rectifier are shown in Figure 35-4.

35-3 Triode Amplifiers

The three-element vacuum tube, or *triode,* has a third element, called a *grid,* often constructed in the form of wire mesh inserted between the cathode and plate. The tube elements sometimes take the form of plane structures and sometimes of concentric cylinders. A potential applied to the grid greatly alters the electric field between cathode and plate. Since the grid is close to the cathode, a small change in grid potential exercises considerable control on the electron current flowing from cathode to plate.

The plate current i_b is a function of two variables, the grid-cathode potential difference ε_c and the cathode-plate potential difference ε_b. The operation of the triode is best analyzed in terms of the static tube characteristics, shown for a typical triode in Figure 35-5.

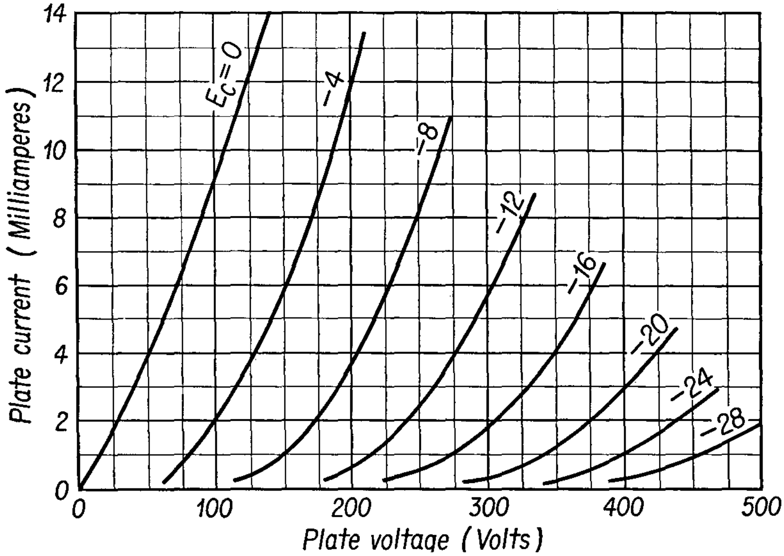

Fig. 35-5 Plate characteristics of the 6C5 triode. (Graph courtesy of General Electric Company.)

In general, we are not interested in the steady or direct current or the fixed electrode potentials except as a means of establishing the operating point of the tube. It is of greater interest to examine the increments in current associated with small increments in the voltage of one or another of the tube elements. Thus we may define the incremental or dynamic *plate resistance* r_p of a tube as the change in the plate-cathode potential difference $\Delta\varepsilon_b$ divided by the resulting change in plate current Δi_b when the other tube element is held at constant potential. Thus

$$r_p = \frac{\Delta\varepsilon_b}{\Delta i_b} \quad ; \quad (\varepsilon_c = \text{const}). \tag{35-3}$$

A second widely used tube characteristic is the *mutual conductance* g_m. The mutual conductance is defined as the change in plate current Δi_b which results from a change in grid potential $\Delta\varepsilon_c$ when the plate potential ε_b is held constant. Thus

$$g_m = \frac{\Delta i_b}{\Delta\varepsilon_c} \quad ; \quad (\varepsilon_b = \text{const}). \tag{35-4}$$

The amplification factor μ is the ratio of the change in plate potential

$\Delta\varepsilon_b$ to the change in grid potential $\Delta\varepsilon_c$ required to produce equal and opposit changes in plate current. If the plate potential is increased by an amount $\Delta\varepsilon_b$ and the grid potential is altered by $-\Delta\varepsilon_c$, there will be no change in the plate current. We have

$$\mu = -\frac{\Delta\varepsilon_b}{\Delta\varepsilon_c}\ ;\ (i_b = \text{const}). \tag{35-5}$$

These three tube parameters are related by the equation

$$\mu = r_p g_m. \tag{35-6}$$

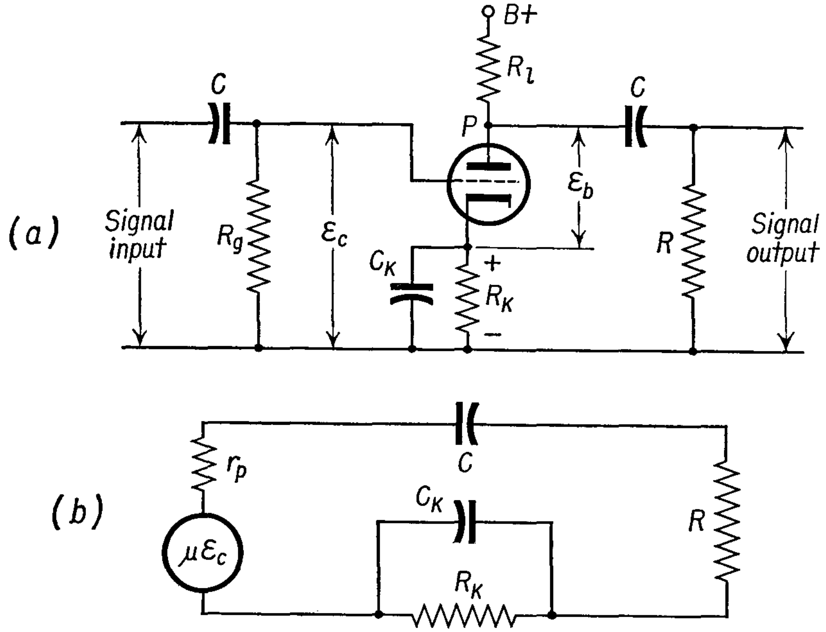

Fig. 35-6 (a) One-stage triode amplifier; grid bias is provided by the voltage drop across the cathode resistor R_K. (b) Equivalent circuit of the amplifier. The combination of R_K and C_K is of negligible impedance at the intermediate signal frequencies, as is the capacitor C.

The values of the plate resistance, the mutual conductance, and the amplification factor are not constant for most tubes and depend upon the operating conditions. Vacuum tubes are nonlinear devices which generally do not obey Ohm's law. Nevertheless, it is often convenient to consider that these parameters are constant for small changes in operating conditions, and to treat the tube as a linear device in discussing vacuum-tube circuits and in preliminary design of such circuits.

A typical schematic circuit of a one-stage triode amplifier is shown in Figure 35-6(a). A power supply consisting of a full-wave rectifier and suitable filters provides a constant positive potential, shown on the figure only as B^+. By suitable choice of a cathode resistor R_k, the IR_k voltage drop in the cathode resistor establishes the cathode at a suitable positive voltage with respect to the grid, called the *grid bias.*

An input signal is applied to the grid resistor R_g. The variations in grid potential cause the plate current to vary, so that a varying potential is generated at the point P. This varying potential is the output signal of the tube. Since the potential of the point P varies about some high positive potential, it is necessary to connect the point P to a blocking capacitor C, and to take the varying signal output from the opposite terminal of the blocking capacitor, whose function is to permit varying currents to flow while preventing the passage of steady currents. The capacitor C blocks the passage of direct current but permits the passage of alternating current.

One way of analyzing the behavior of such a circuit is to imagine the tube to be replaced by an electrical generator whose emf is $\mu \varepsilon_c$ and whose internal resistance is r_p, as shown in Figure 35-6(b). The signal voltage appearing across the load resistor may then be obtained by the application of principles of network analysis.

In this simplified discussion of the operation of a vacuum-tube amplifier, we have neglected the existence of interelectrode capacitances and other limiting effects. Any pair of conductors separated by a nonconductor constitutes a capacitor; there is thus a capacitance between the grid and cathode and between the grid and plate. These interelectrode capacitances are in parallel with the grid resistor. At high frequencies the impedance of the grid network is greatly reduced. This means that the amplification of a vacuum-tube amplifier drops off at high signal frequencies unless special precautions are taken in the design of the tube itself. At low frequencies the coupling capacitor C plays a dominant role in establishing the sensitivity of an amplifier, for it is in series with the resistor R. The voltage division between C and R is frequency dependent, and the amplified signal drops off at low frequencies.

35-4 Other Electron Tubes

Many other electron tubes have been designed for special purposes. In a *tetrode,* or four-element tube, an additional grid, called a *screen grid,* is inserted between the plate and control grid to reduce the interelectrode plate-to-grid capacitance. In a *pentode,* or five-element tube, another grid, called a *suppressor grid,* is installed between the plate and screen grid. Its purpose is to repel secondary electrons back to the plate; these would tend to go to the more positive screen grid in a pentode operating at low plate voltage.

A *photoelectric cell* has a plate coated with a metal of low work function so that it emits photoelectrons when illuminated with light. The photoelectrons are collected by a positive collector electrode; the current through the tube depends upon the intensity of the incident light.

A *cathode-ray* tube, shown in Figure 35-7, is one in which a focused beam of electrons from the cathode is accelerated by a series of electrodes and caused to strike the phosphor on the screen at a point; the phosphor fluoresces when struck by rapidly moving electrons. The electron beam is deflected by transverse electric or magnetic fields and can be made to produce a pattern on the screen if the deflecting field is varied. Such a tube is widely used in the laboratory in a device called a cathode-ray oscillograph. In a television set the electron beam is swept across the face of the screen in a series of lines. The intensity of the beam is caused to vary in accordance with the signal transmitted from the television station, producing a pattern of light and dark areas on the screen which we see as a picture.

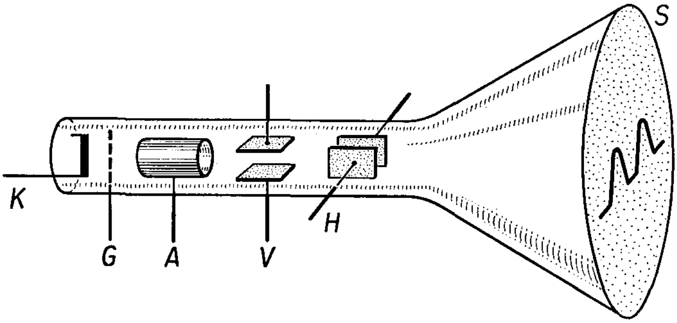

Fig. 35-7 Cathode-ray tube showing cathode K, grid G, anode A, vertical deflection plates V, horizontal deflection plates H, and screen S. Thermally emitted electrons are accelerated and focused by the anode to strike the screen.

A *photomultiplier* tube, shown in Figure 35-8, achieves a high output signal by the process of secondary emission. A small number of photoelectrons, emitted from the photoelectric surface, is accelerated by the electric field and caused to strike the first plate or *dynode*. Several secondary electrons are emitted by the dynode for each primary electron which strikes it. These secondary electrons are accelerated and caused to strike a second dynode, and so on, so that after striking some nine dynodes there are about 10^5 to 10^7 electrons collected by the plate for every photoelectron emitted from the photoelectric surface.

In addition to the vacuum tubes in which the electron is the conductor of electricity, there are many tubes filled with gas at low pressure, in which

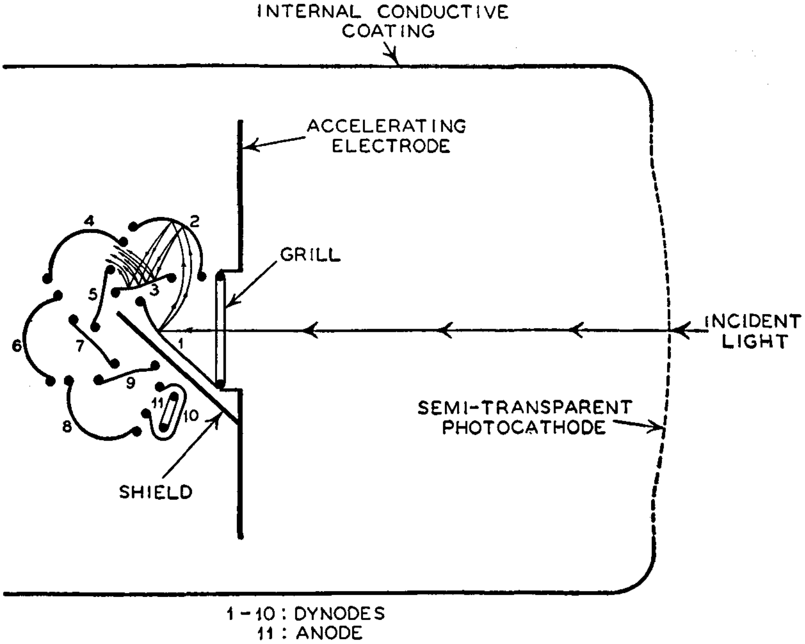

Fig. 35-8 Photomultiplier tube. Schematic diagram showing arrangement of electrode structure. (Courtesy of RCA Victor Division.)

gaseous ions and electrons are the carriers of electricity. In fluorescent lighting units, to be discussed in a subsequent chapter, the gas is used as a source of light. Gaseous rectifier tubes are often used to carry currents larger than can be carried in vacuum-tube diodes. Some gas tubes have the special property that the voltage across the tube is practically independent of the current through the tube. These tubes are used as *voltage regulators*, for, if they are connected across a particular load, the voltage supplied to the load remains constant, regardless of the fluctuation in line voltage.

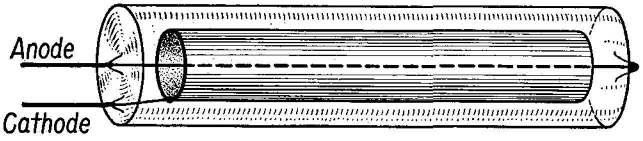

Fig. 35-9 Geiger counter tube.

The *Geiger-counter* tube, shown in Figure 35-9, is a special gas tube which is widely used in nuclear physics. Here a cylindrical anode surrounds a cathode made of a fine wire. The space between the anode and cathode is filled with a gas at low pressure, approximating 1/10 atm, and a high voltage is applied to the tube. If incident radiations have sufficient energy to ionize a few of the molecules of the gas, the electric field is high enough to accelerate these ions so that they will cause additional ionization when they collide with other gas molecules. In this way an avalanche of gaseous ions is created, and a large burst of current passes through the tube whenever ionizing radiation penetrates the tube.

35-5 Transistors

We have already seen in Section 28-4 that it is possible to construct a rectifier, called a semiconductor diode, from a semiconducting crystal. It is also possible to assemble semiconducting crystals into a device which has properties similar to those of a vacuum-tube triode. Such a device is called a *transistor.*

We will recall that a crystal of germanium, which itself has 4 valence electrons, can be altered by the presence of an antimony impurity, which has 5 valence electrons, so that the excess valence electron can migrate through the crystal. A germanium crystal with this type of impurity is called an n-type semiconductor, for its conductivity is due to negative carriers of electricity.

If indium, having only 3 valence electrons, is introduced as an impurity in germanium, there is a deficiency of electrons at the location of the impurity, and electrons from the germanium may migrate to and from the impurity site. In this case we may think of the hole, or vacancy, as the carrier of electricity, and we designate such semiconductors as p-type semiconductors, for the carrier of electricity may be thought to be the "positive hole."

A transistor is a crystal having two p-type regions separated by an n-type region, in which case it is known as a p-n-p transistor, or having two n-type regions separated by a p-type region, in which case it is called an n-p-n transistor. Figure 35-10 is a schematic diagram of an n-p-n transistor. The electrode connected to the p region is called the *base.* One electrode connected to an n region is called the *emitter,* and the other electrode is connected to the other n region and is called the collector.

The behavior of a transistor can be demonstrated by connecting one battery B_1 so that the base is positive with respect to the emitter, while a second battery B_2 is connected so that the base is negative with respect to the collector. The voltage bias on the collector is positive with respect to the base. As we have seen in Section 28-4, the direction of easy flow in a transistor diode occurs when the n region is connected to the negative terminal of a battery and the p region is connected to the positive terminal. Thus the collector-base interface will have a high resistance when the emitter-base interface has a low resistance. If the thickness of the intermediate p region is very small, many electrons from the n region on the left will diffuse through the p region without combining with a hole, and will diffuse into the p region on the right toward the collector. Practically all of the current flowing from the emitter will pass to the collector electrode, while a very small current flows from the base to either the emitter or the collector.

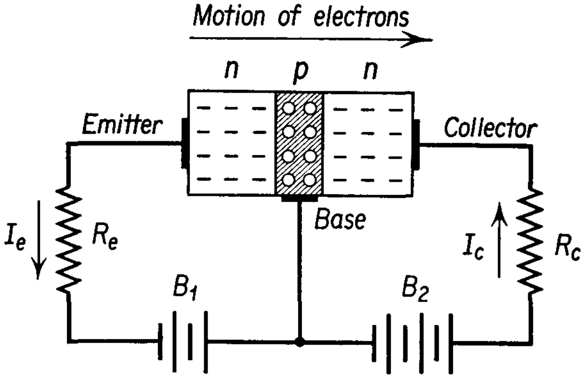

Fig. 35-10 Schematic diagram of the n-p-n transistor.

The base may be likened to the grid of a vacuum triode, the emitter to the cathode, and the collector to the plate. The current flowing from the emitter to the collector depends upon the voltage applied to the base. The signal to be amplified is connected between the emitter and the base. Because of the way the bias voltage is applied, the resistance of the path from emitter to base is small compared to the resistance between emitter and collector.

If we call the current in the emitter branch I_e and the resistance of this branch R_e, the power developed in it is $I_e^2R_e$. Similarly, the power developed in the collector branch is $I_c^2R_c$, where I_c is the current in the collector branch, and R_c is its resistance. The value of R_c is usually much greater than R_e, mainly because of the way the electric fields produced by the batteries B_1 and B_2 are biased in the different sections of the crystal. The ratio of the power delivered to the collector to that in the emitter is

$$\frac{I_c^2R_c}{I_e^2R_e}.$$

Even though I_c may be only slightly larger than I_e, there will still be a large gain in power in the ratio R_c/R_e. The power gain may be as high as 10^5.

The transistor has several advantages over vacuum tubes in many circuit applications. Since there is no filament to heat, the power consumed by the transistor is very small. The transistor is light in weight and of small physical size. The transistor has good inherent mechanical stability as compared to a vacuum tube, for there are no tube elements whose position may be altered by vibration or shock. At the present time the transistor is limited to the production of small amounts of signal power, of the order of several watts, as compared to a power output of the order of kilowatts which may be obtained from vacuum tubes used in radio transmitters.

35-6 Radiation of Electromagnetic Waves

An electric charge which moves with constant speed in a straight line can radiate no energy. Only when the charge is being accelerated will it radiate electrical energy. A charge, moving at velocities which are small compared to the velocity of light in vacuum, does not radiate energy uniformly in all directions. The radiation is a maximum in a direction perpendicular to the direction of the acceleration and is zero in the direction of the acceleration. The rate of radiation of electromagnetic energy from an accelerated charged particle is given by

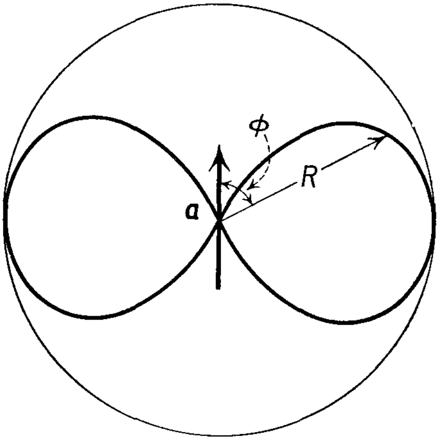

Fig. 35-11 Polar plot of relative rate of radiation from a charged particle whose acceleration vector is **a** in directions making an angle ϕ with the direction of the acceleration; the radius vector R from the position of the particle to the curve is proportional to the rate of radiation in the direction of R.

$$S = \frac{2}{3}\frac{q^2}{c^3}a^2,$$

where S is the rate of radiation in ergs per second from a particle of charge q stcoul moving with an acceleration of a cm/sec^2; $c = 3 \times 10^{10}$ cm/sec. The relative intensity of radiation in directions making an angle ϕ with the direction of the acceleration vector depends upon a factor $\sin^2 \phi$ and is plotted in Figure 35-11.

A steady current in a wire may be considered as being composed of a collection of charges moving with constant velocity. Thus no radiation results from direct current in a wire. Only when the current in the wire is changing is there radiation. Thus, whenever a switch is closed, or whenever there is an impulsive flow of charge, as in an automobile ignition system, we must expect electromagnetic radiation to take place. Indeed, this is the reason for the interference observed on radio and television sets caused by passing automobiles.

When a charge is oscillating in simple harmonic motion with angular frequency ω and amplitude A, the magnitude of the acceleration varies with the displacement in accordance with Equation (12-7).

$$a = \omega^2 A \cos \omega t.$$

Since the rate of radiation depends upon the instantaneous acceleration of the charged particle, the energy radiated from an oscillating charge must display the same time variation, hence must have the same frequency, as the charged particle. In addition we note that the magnitude of the acceleration varies with the amplitude A of the simple harmonic motion and with the square of the frequency ω^2. We must therefore expect a greater rate of radiation from an oscillating charged particle when that particle oscillates at higher frequencies.

A transmitting antenna consists of a wire or some other electrical conductor connected to an oscillator. The antenna may be thought of as a capacitor which becomes charged and discharged as the emf of the oscillator alternates. Electric charges flow to and from the antenna with the frequency of the oscillator. We may relate the behavior of the antenna as a radiator of electromagnetic waves to the radiation from oscillating charged particles.

With the restriction that the antenna is short compared to its wave length (to avoid the complication of standing waves), the longer the antenna, the greater the amplitude of oscillation of the electric charges whose motion constitutes the current. Therefore, a long antenna is a more effective radiator than a short one. Furthermore, the energy radiated depends upon the square of the frequency of oscillation. We must therefore expect the fraction of the energy to be radiated from a 60-cycle power line to be small under the same circumstances that the energy radiated from a 1-megacycle radio antenna is quite large.

The energy which is radiated leaves the antenna in the form of an electromagnetic wave, consisting of an oscillating electric field and an oscillating magnetic field which are coupled together. The changing magnetic field may be thought to generate an electric field in accordance with Faraday's law of induction. The changing electric field may be thought of as though it were generated by a virtual alternating current, called the *displacement current,* which generates a magnetic field in accordance with Ampère's law. This exchange of energy between electric and magnetic fields constitutes a wave motion which is propagated with the velocity of light.

Practical antennae are not quite so simple as those we have discussed here, but any element of conductor carrying current may be considered as the source of the wave, and the radiation from the antenna as a whole may be calculated from Huygens' principle. In general, the reciprocal relation between radiation and absorption developed in our discussion of black-body radiation is equally applicable here. Thus an antenna which is an effective transmitter of electromagnetic radiation will also be effective as an absorber of radiation, hence a good receiving antenna.

The mechanism by which an antenna receives a signal transmitted by electromagnetic radiation is the inverse of the mechanism by which it transmits radiation. The passing electromagnetic field induces currents in the antenna which alternate with the frequency of the radiation. These currents flow through a resistor and are subsequently amplified and converted into a useful signal in the receiving set.

Like the transmission of light, the transmission of electromagnetic waves is along the line of sight. Radio communication is received at large distances from the transmitting antenna, at points obscured from the antenna by the curvature of the earth, by reflection from a region of ionized atmosphere known as the *ionosphere,* or the *Kennelly-Heaviside* layer, located at high altitudes. This layer of ionization behaves like an electrical conductor at some frequencies. Radiation at these frequencies may be reflected back and forth between the earth and the ionosphere, so that it is propagated halfway around the earth. The ionosphere is generated by the action of solar radiation upon the atmosphere. Solar flares and other solar disturbances affect the ionization and consequently affect radio transmission and reception at large distances from a transmitting antenna.

Problems

35-1. The peak current in a half-wave rectifier is 100 ma. Find the effective or rms current from this rectifier.

35-2. In the circuit of Figure 35-3(a), the applied 60-cycle alternating emf has a peak or maximum voltage of 150 volts. Find the peak values of (a) the current through the load resistor and (b) the voltage across it when it has a resistance of 500 ohms.

35-3. In the full-wave rectifier of Figure 35-4(a), the applied 60-cycle alternating emf is 300 volts rms across the entire secondary winding of the transformer. The load resistance R_L = 500 ohms. Find (a) the peak current through the load resistor and (b) the peak voltage across it.

35-4. Find the plate resistance, the amplification factor, and the mutual conductance of the triode of Figure 35-5 when the plate voltage is 200 volts and the grid bias is (a) -12 volts and (b) -8 volts.

35-5. Find the plate current in a 6C5 triode whose static characteristics are given in Figure 35-5 when its cathode is connected to the negative terminal of a 300-volt battery, its plate is connected to the anode of the battery through a 30,000-ohm resistor, and $\mathcal{E}_c = -4$ volts.

35-6. A triode amplifier has an amplification factor of 20 and a plate resistance of 10,000 ohms. What is the gain of the amplifier when the plate load resistor is 20,000 ohms? Draw the equivalent circuit of the amplifier.

35-7. The change in plate current of a triode may be expressed as the sum of two terms, for the change in plate current Δi_b may be due to the change in plate potential $\Delta \mathcal{E}_b$ and to the change in grid potential $\Delta \mathcal{E}_c$, as

$$\Delta i_b = \frac{1}{r_p} \Delta \mathcal{E}_b + g_m \Delta \mathcal{E}_c.$$

From the above expression prove that

$$g_m r_p = \mu.$$

35-8. A two-stage amplifier has a gain of 10^3. What is the gain of each stage, assuming these to be equal.

35-9. In a television set, a ghost pattern caused by reflection of the signal from a distant building is observed to follow the main pattern by 1 μsec. What is the difference in the length of the path from the transmitter to the tube between the direct signal and the reflected signal?