band and (except for the degenerate case) the number of carriers decreases as $\exp(-q\Delta V/kT)$ where $\Delta V$ is the spacing between the Fermi level and the band concerned, and $q$ is the electronic charge. As a consequence of the small number of holes in the $N_c$ region and electrons in the P region, very small currents flow across the barrier and the reverse direction has high resistance.

In diagram *d* of Fig. 11, the additional effect of applying a voltage in the forward direction across the $N_e$-P or left-hand barrier is shown. This is the forward direction for this barrier, and electrons tend to flow from $N_e$ to P. This current builds up exponentially with the voltage difference between $V_1$ and $V_2$. At the same time holes flow from P to $N_e$. However, for the structure shown, the hole current will be much smaller than the electron current; the reason for this being essentially that since more electrons are available in $N_e$ than holes in P as determined by the configuration of the device, more electrons will flow than holes for a given potential difference. The electrons which flow to P will diffuse thermally in P. Also they will drift in any field which is present. As a result they will get over the maximum in P and flow to $N_c$, and thence to electrode C.

It should be noted that there are several other ways of reducing the hole current from P to $N_e$ Two of these are illustrated in Fig. 12. Diagrams *a* and *b* of this figure correspond to equilibrium or zero current situations for the device under consideration. Under these conditions the number of holes in region $N_e$ is determined by the potential energy difference $U_1$. If the potential difference is applied between $N_e$ and P in the forward direction across the barrier as is shown in Fig. 11D for example, then the concentration of holes in $N_e$ due to flow from P will tend to increase exponentially with the voltage difference $V_2-V_1$. Similarly the concentration of electrons flowing from $N_e$ to P will tend to increase exponentially in the same way starting with a value determined by $U_2$. Hence, if $U_2$ is initially less than $U_1$ the tendency of electrons to flow from $N_e$ to P will be greater than the tendency of holes to flow from P to $N_e$.

All of the cases considered in Figs. 11 and 12 are designed so as to produce this desirable difference between $U_2$ and $U_1$. In Figs. 11 and 12*a* this is accomplished by having different concentrations of impurities in $N_e$ and P in such a way that the net concentration of the electrons in $N_e$ is greater than the concentration of holes in P. In Fig. 11 the electron concentration is so high that a degenerate situation exists whereas in Fig. 12*a* a non-degenerate situation is shown. In Fig. 12*b* this effect is further enhanced by using two different semiconductors. The semiconductor used for $N_e$ has a wider energy gap since it is N-type. This increases the value of $U_1$ compared to $U_2$ in the P region. For example the $N_e$ zone may be of N-type silicon and the other two zones of P and N-type germanium respectively.

If we idealize the structure for the moment and neglect any resistances at the metal semiconductor contacts, and the hole current between P and $N_e$, the comparison between this device and a vacuum tube becomes clear. In place of the grid, there is the P region, which can be charged in respect to $N_e$ by holes. This modulates the flow of electrons from $N_e$ into P just as the charge on the grid modulates the flow of electrons from the cathode. The charging current to P, consisting of holes, does not flow to $N_c$ any more than does the charging current to the grid. Thus the fact that there are two processes of conduction through the P region permits control to take place in a way similar to that in the vacuum tube.

Before considering how the above description should be modified when neglected features are taken into account, consideration may be given to the feature common to devices which amplify alternating current power using a direct current power supply. Such devices have an input and an output circuit, and for purposes of discussion may be regarded as four terminal devices. Into the pair of input terminals there flows direct current and alternating current power ($P_{idc}$ and $P_{iac}$) and into the output terminals there is a similar flow ($P_{odc}$ and $P_{oac}$). For a steady state condition, the second law of thermodynamics requires that the sum of all these powers is positive. For an amplifier, however, $P_{oac}+P_{iac}$ is negative, meaning that the device gives out alternating current power. In a conventional circuit the power is taken out between plate and cathode and the alternating current and voltage under operating conditions are like those of a negative resistance. That is, when the plate potential swing is negative, the plate current swing (i. e., current into the tube, or electrons out) is positive. The reason for this behavior is that the plate impedance is relatively high. Hence, when the grid swing is plus the plate current is increased over the direct current value and remains increased even though a negative plate swing occurs. Hence, power can be delivered to the plate.

The $N_c$-P barrier acts in much the same way as the grid-plate region of the vacuum tube. There is a steady reverse current; however, this is relatively insensitive to plate potential. The electron current due to the difference in potential between E and B, is also relatively insensitive to collector voltage since once the electrons have passed the maximum potential point in P they are practically certain to be drawn to C. Hence the alternating current across the $N_c$-P barrier can be made out of phase with the voltage on C and output power can be delivered.

Next there may be taken into account the fact that there is actually a current flowing to B which may absorb input power. This current arises from several sources. Holes from $N_c$ will flow to P and also some holes from P will flow to $N_e$. Both of these currents tend to lower the impedance of B and require more power to drive it. Also, since B is positive some electrons entering P tend to flow to the electrode B thus contributing still another source of power absorption. Holes and electrons will also combine in P at an enhanced rate compared to thermal equilibrium because both the hole and the electron concentrations in P are appreciably greater than normal. This requires an additional hole current into P from B. However, proper geometrical requirements can be met so that these currents are sufficiently minimized to permit substantial power amplification.

The reason for this is that so long as the P layer is not too thick, an appreciable fraction of the electrons flowing from $N_e$ into P will continue to $N_c$. This means that the alternating current components of current in C will be comparable to the alternating currents in E and B. As will be pointed out later, a proper condition adjacent electrode C may actually lead to larger alternating current components in C than in either E or B. Furthermore, the impedance between E and B is relatively low since the $N_e$-P junction is operated in the forward direction. Since power is $I^2R$, and since the input and output currents are com-