The integral in Eq. (3.53) is the same Fermi–Dirac integral defined by Eq. (3.52), although the variables have slightly different definitions. We may note that if $n_F' > 0$, then the Fermi level is in the valence band.

3.4.4 Degenerate and Nondegenerate Semiconductors

In our discussion of adding dopant atoms to a semiconductor, we have implicitly assumed that the concentration of dopant atoms added is small when compared to the density of host or semiconductor atoms. The small number of impurity atoms are spread far enough apart so that there is no interaction between donor electrons, for example, in an *n*-type material. The few impurity atoms were so widely spaced throughout the sample, we can say that no charge transport could take place within the donor or acceptor levels. We have assumed that the impurities introduce discrete, noninteracting donor energy states in the *n*-type semiconductor and discrete, noninteracting acceptor states in the *p*-type semiconductor. These types of semiconductors are referred to as nondegenerate semiconductors.

If the impurity concentration increases, the distance between the impurity atoms decreases and a point will be reached when donor electrons, for example, will begin to interact with each other. When this occurs, the single discrete donor energy will split into a band of energies. As the donor concentration further increases, the band of donor states widens and may overlap the bottom of the conduction band. This overlap occurs when the donor concentration becomes comparable with the effective density of states. When the concentration of electrons in the conduction band exceeds the density of states N_c, the Fermi energy lies within the conduction band. This type of semiconductor is called a degenerate *n*-type semiconductor.

In a similar way, as the acceptor doping concentration increases in a *p*-type semiconductor, the discrete acceptor energy states will split into a band of energies and may overlap the top of the valence band. The Fermi energy will lie in the valence band when the concentration of holes exceeds the density of states N_v. This type of semiconductor is called a degenerate *p*-type semiconductor.

Schematic models of the energy-band diagrams for a degenerate *n*-type and degenerate *p*-type semiconductor are shown in Fig. 3.19. The energy states below E_F are mostly filled with electrons and the energy states above E_F are mostly empty. In the degenerate *n*-type semiconductor, the states between E_F and E_c are mostly filled

Class : BE | Course / Branch : Electronics | Subject: IC Technology | To:
No. of Lectures Scheduled (S) : | Sem: VII | Division:

with electrons; thus, the electron concentration in the conduction band is very large. Similarly, in the degenerate *p*-type semiconductor, the energy states between E_v and E_F are mostly empty; thus, the hole concentration in the valence band is very large.

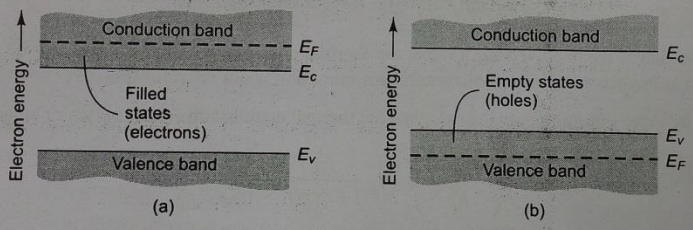

Fig. 3.19 *Simplified energy-band diagrams for degenerately doped (a) n-type, and (b) p-type semiconductors*

3.5 STATISTICS OF DONORS AND ACCEPTORS

In the last chapter, we discussed the Fermi–Dirac distribution function, which gives the probability that a particular energy state will be occupied by an electron. We need to reconsider this function and apply the