It therefore follows that, if \( E_v + 3kT \leq E_F \leq E_c - 3kT \),

\[
\begin{align*}
  n &= N_c e^{(E_F - E_v)/kT} \\
  p &= N_v e^{(E_c - E_F)/kT}
\end{align*}
\]  

(2.16a)  

(2.16b)

The mathematical simplification leading to Eqs. (2.16) is equivalent to approximating the filled-state and empty-state occupancy factors by exponential functions — an approximation earlier shown to be valid provided \( E_F \) was somewhere in the band gap no closer than \( 3kT \) to either band edge. Whenever \( E_F \) is confined, as noted, to \( E_v + 3kT \leq E_F \leq E_c - 3kT \), instead of continually repeating the \( E_F \) restriction, the semiconductor is simply said to be nondegenerate. Whenever \( E_F \) lies in the band gap closer than \( 3kT \) to either band edge or actually penetrates one of the bands, the semiconductor is said to be degenerate. These very important terms are also defined pictorially in Fig. 2.19.

### 2.5.2 Alternative Expressions for \( n \) and \( p \)

Although in closed form, the Eq. (2.16) relationships are not in the simplest form possible, and, more often than not, it is the simpler alternative form of these relationships which one encounters in device analyses. The alternative-form relationships can be obtained by recalling that \( E_F \), the Fermi level for an intrinsic semiconductor, lies close to midgap, and hence Eqs. (2.16) most assuredly apply to an intrinsic semiconductor. If this be the case, then specializing Eqs. (2.16) to an intrinsic semiconductor, i.e., setting \( n = p = n_i \) and \( E_i = E_F \), one obtains

\[
  n_i = N_c e^{(E_i - E_v)/kT}
\]  

(2.17a)

\[
  p_i = N_v e^{(E_c - E_i)/kT}
\]  

(2.17b)

---

Fig. 2.19 Definition of degenerate/nondegenerate semiconductors.