(i) Compensation and Space Charge Neutrality

Figure below illustrates a semiconductor for which both donors and acceptors are present, but $N_D > N_A$. The predominance of donors makes the material *n*-type and the Fermi level is therefore in the upper part of the band gap. Since E_F is well above the acceptor level E_a, this level is essentially filled with electrons. However, with E_F above E_i we cannot expect a hole concentration in the valence band commensurate with the acceptor concentration. In fact, the filling of the E_a states occurs at the expense of the donated conduction band electrons.

The mechanism can be visualized as follows: Assume an acceptor state is filled with a valence band electron, with a hole resulting in the valence band. This hole is then filled by recombination with one of the conduction band electrons. Extending this logic to all the acceptor atoms, we expect the resultant concentration of electrons in the conduction band to be $N_D - N_A$ instead of the total N_D. This process is called *compensation*. By this process it is possible to begin with an *n*-type semiconductor and add acceptors until $N_A = N_D$ and no donated electrons remain in the conduction band. In such compensated material $n_0 = n_i = p_0$ and intrinsic conduction is obtained. With further acceptor doping the semiconductor becomes *p*-type with a hole concentration of essentially $N_A - N_D$.

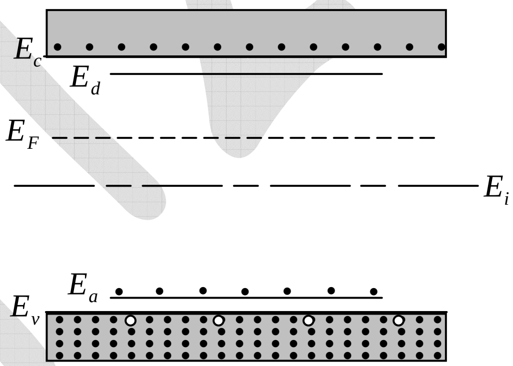

Figure: Compensation in an *n*-type semiconductor $(N_D > N_A)$.

The exact relationship among the electron, hole, donor, and acceptor concentrations can be obtained by considering the requirements for ***space charge neutrality***. If the material is to remain electrostatically neutral, the sum of the positive charges (holes and ionized donor atoms) must balance the sum of the negative charges (electrons and ionized acceptor atoms):

$$p_0 + N_D^+ = n_0 + N_A^-$$

Thus the net electron concentration in the conduction band is $n_0 = p_0 + (N_D^+ - N_A^-)$.

If the material is doped *n*-type $\left(n_0 \gg p_0\right)$ and all the impurities are ionized, we can approximate that $n_0 = N_D - N_A$.

Since the intrinsic semiconductor itself is electrostatically neutral and the doping atoms we add are also neutral, the requirement of equation $p_0 + N_D^+ = n_0 + N_A^-$ must be maintained at equilibrium.

Knowledge of carrier concentrations in a solid is necessary for calculating current flow in the presence of electric or magnetic fields. In addition to the values of *n* and *p,* we must be able to take into account the collisions of the charge carriers with the lattice and with the impurities. These processes will affect the ease with which electrons and holes can flow through the crystal, that is, their mobility within the solid. As should be expected, these collision and scattering processes depend on temperature, which affects the thermal motion of the lattice atoms and the velocity of the carriers.