(e) Extrinsic Material

In addition to the intrinsic carriers generated thermally, it is possible to create carriers in semiconductor purposely by introducing impurities into the crystal. This process, called *doping* is the most common technique for varying the conductivity of semiconductors. By doping, a crystal can be altered so that it has a predominance of either electrons or holes. Thus there are two types of doped semiconductors, ***n*-type** (mostly electrons) and ***p*-type** (mostly holes).

When impurities or lattice defects are introduced into an otherwise perfect crystal, additional levels are created in the energy band structure usually within the band gap. For example, an impurity from column V of the periodic table (*P*, *As*, and *Sb*) introduces an energy level very near the conduction band in *Ge* or *Si*. This level is filled with electrons at $0\,K$, and very little thermal energy is required to excite these electrons to the conduction band. Thus at about $50\,K - 100\,K$ virtually all of the electrons in the impurity level are "donated" to the conduction band. Such an impurity level is called a **donor level** and the column *V* impurities in *Ge* or *Si* are called donor impurities. From figure, we note that the material doped with donor impurities can have a considerable concentration of electrons in the conduction band, even when the temperature is too low for the intrinsic EHP concentration to be appreciable. Thus semiconductors doped with a significant number of donor atoms will have $n_0 >> (n_i, p_0)$ at room temperature. This is ***n*-type** material.

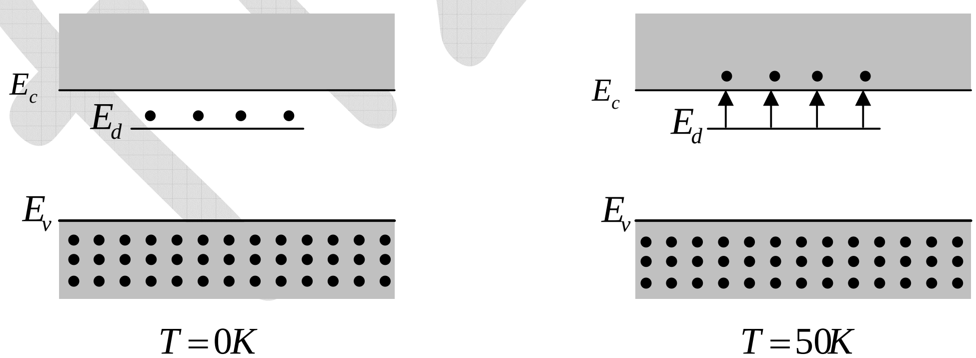

Figure: Donation of electrons from a donor level to the conduction band.

Atoms from column III (*B*, *Al*, *Ga*, and *In*) introduce impurity levels in *Ge* or *Si* near the valence band. These levels are empty of electrons at $0\,K$. At low temperatures, enough thermal energy is available to excite electrons from the valence band into the impurity level, leaving behind holes in the valence band, since this type of impurity level "accepts" electrons from the valence band, it is called an ***acceptor level***, and the column III impurities are acceptor impurities in *Ge* and *Si*. Figure below indicates, doping with acceptor impurities can create a semiconductor with a hole concentration p_0 much greater than the conduction band electron concentration n_0 (this is ***p*-type** material).

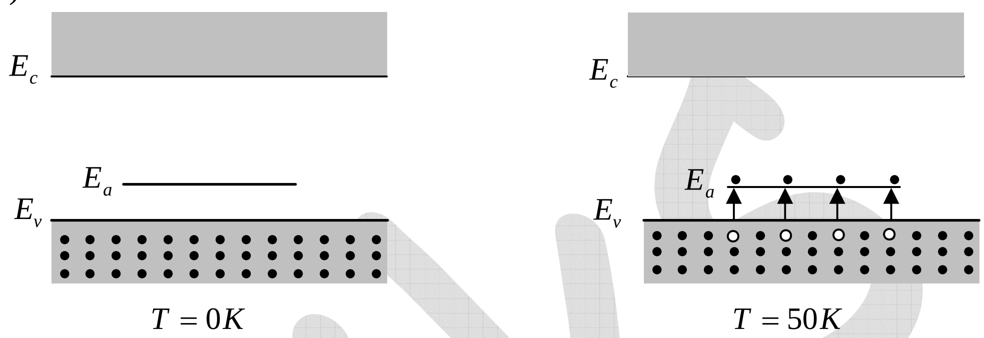

Figure: Acceptance of valence band electrons by an acceptor level, and the resulting creation of holes.