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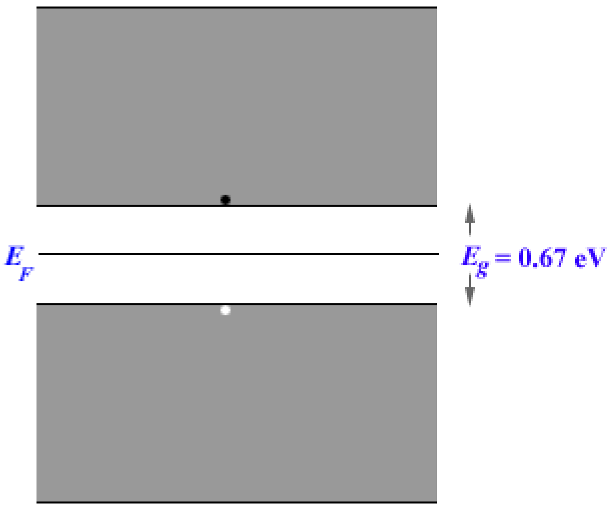
Problem 53.31 (RHK)

The Fermi-Dirac distribution function can be applied to semiconductors as well as to metals. In semiconductors, E is the energy above the top of the valence band. The Fermi level for an intrinsic semiconductor is nearly midway between the top of the valence band and the bottom of the conduction band. For germanium these bands are separated by a gap of 0.67 eV. *We have to calculate the probability that* (a) *a state at the bottom of the conduction band is occupied and* (b) *a state at the top of the valence band is unoccupied at* 290 K.

Solution:



It is given that the Fermi level for an intrinsic semiconductor is nearly midway between the top of the valence band and the bottom of the conduction band. As shown in the figure the conduction band and the valence band are separated by 0.67 eV.

The Fermi-Dirac probability that a state of energy *E* is occupied at temperature *T* is

$$p(E) = \frac{1}{\exp\left(\left(E - E_F\right)/kT\right) + 1},$$

and that a state of energy E is unoccupied or is vacant is $1 - p(E)$. It is given that the Fermi level is midway between the valence band and the conduction band.

Therefore, for a state at the top of the valence band

$$E - E_F = \frac{0.67}{2}\ \text{eV} = 0.335\ \text{eV}.$$

And at a temperature of 290 K,

$$\left((E - E_F)/kT\right) = \frac{0.335}{8.62 \times 10^{-5} \times 290} = 13.40 .$$

Therefore, the probability that there is a hole at the top of the valence band will be

$$p_h(E) = 1 - p(E) = 1 - \frac{1}{e^{-13.40} + 1} \approx e^{-13.40} = 1.51 \times 10^{-6}.$$

The probability for occupation of a state at the bottom of the conduction band will also be

$$p(E) = \frac{1}{e^{+13.40} + 1} \approx e^{-13.40} = 1.51 \times 10^{-6}.$$