Primer on Semiconductors

Unit 3: Equilibrium Carrier Concentrations

Lecture 3.1: The Fermi function

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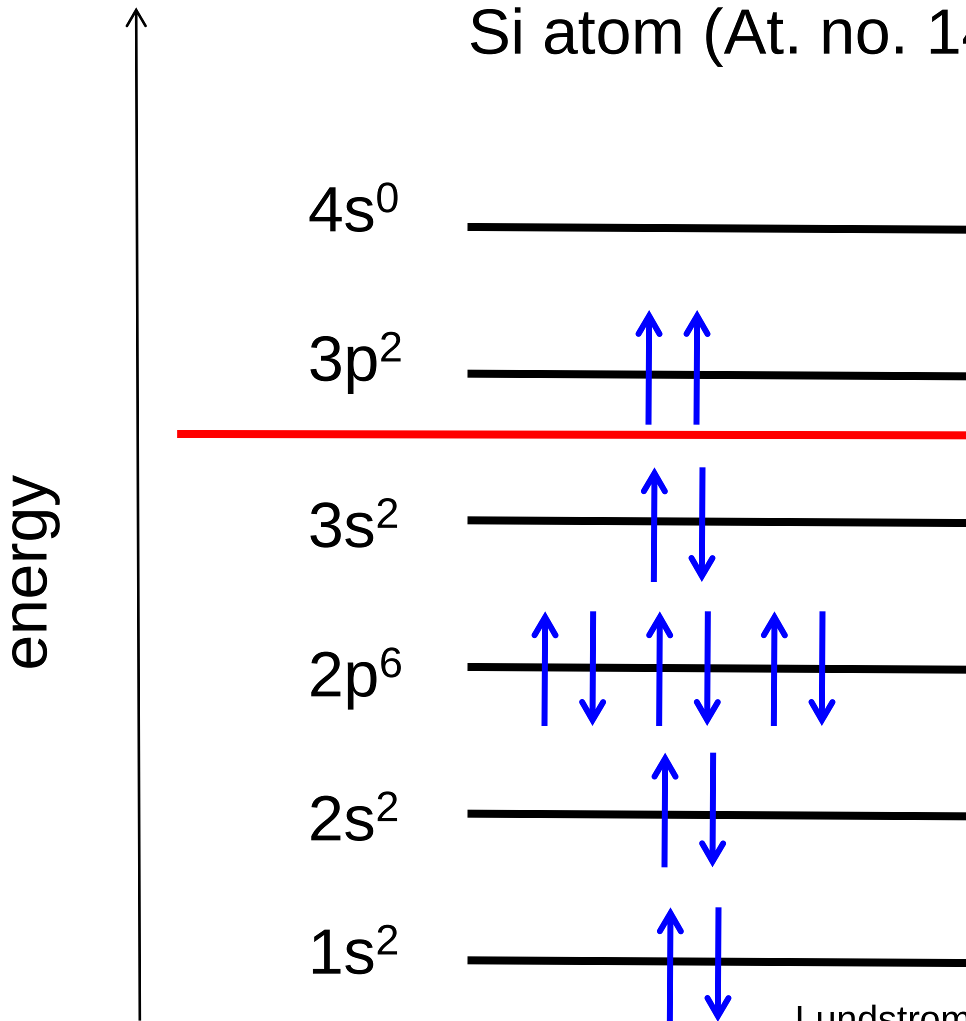
Occupation of states

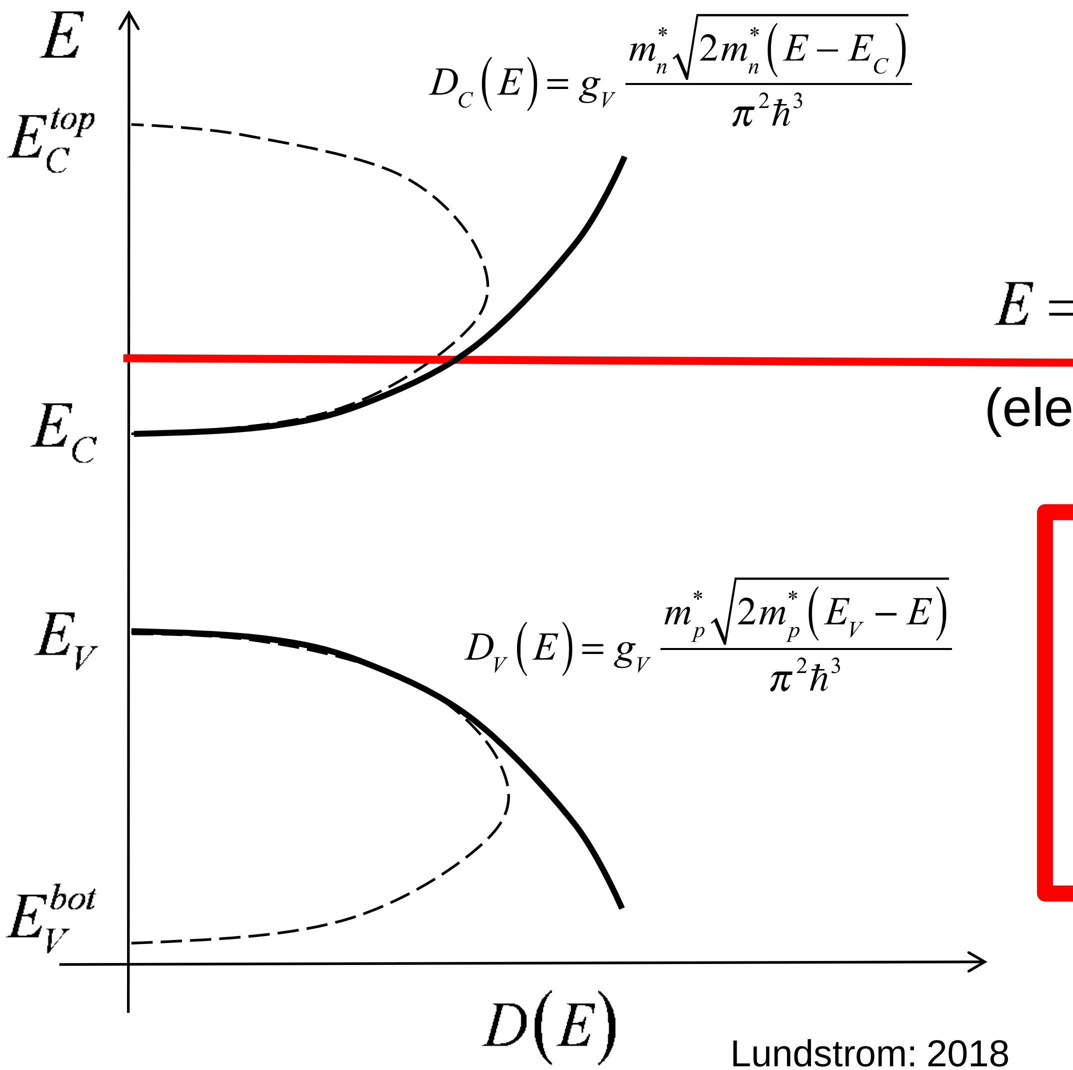
Si atom (At. no. 14)



States above this energy have a low probability of being occupied.

States below this energy have a high probability of being occupied.

Fermi level



$E = E_F$

(electrochemical potential)

$$f_0(E) = \frac{1}{1+e^{(E-E_F)/k_B T}}$$

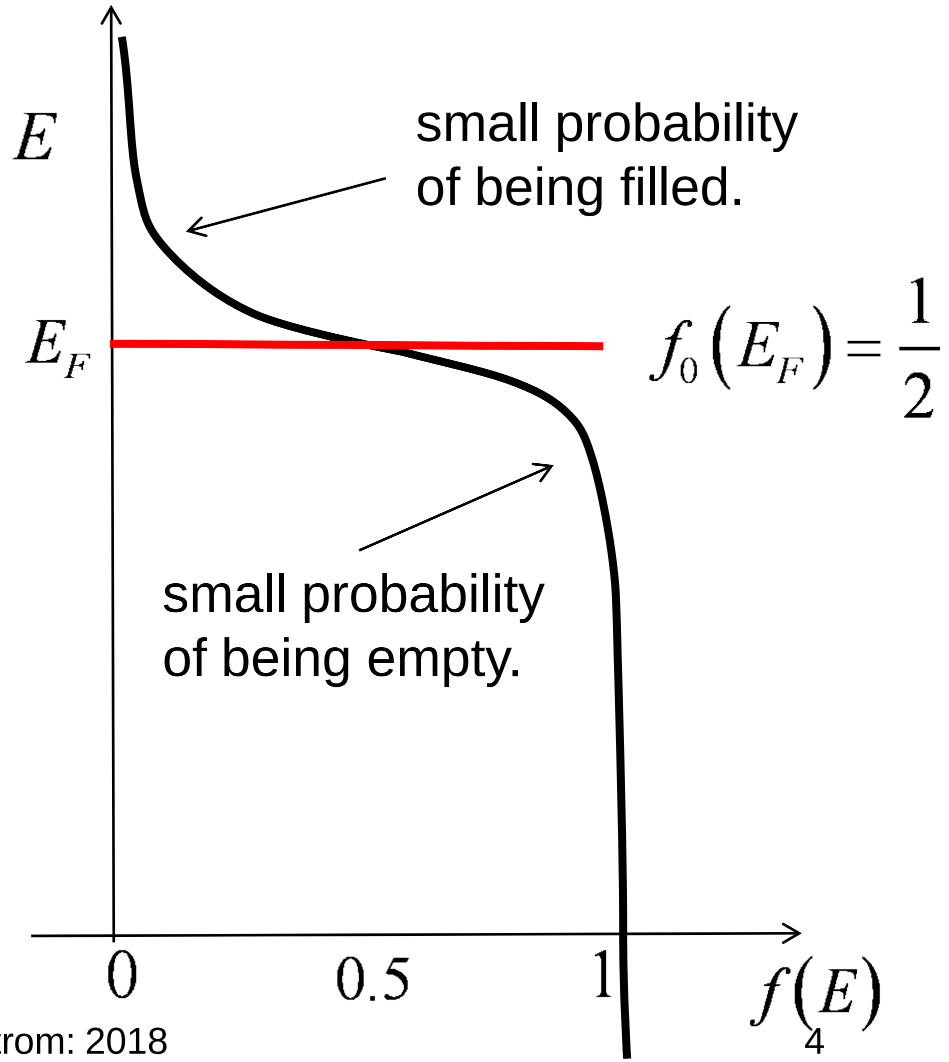
(Fermi function)

The Fermi function

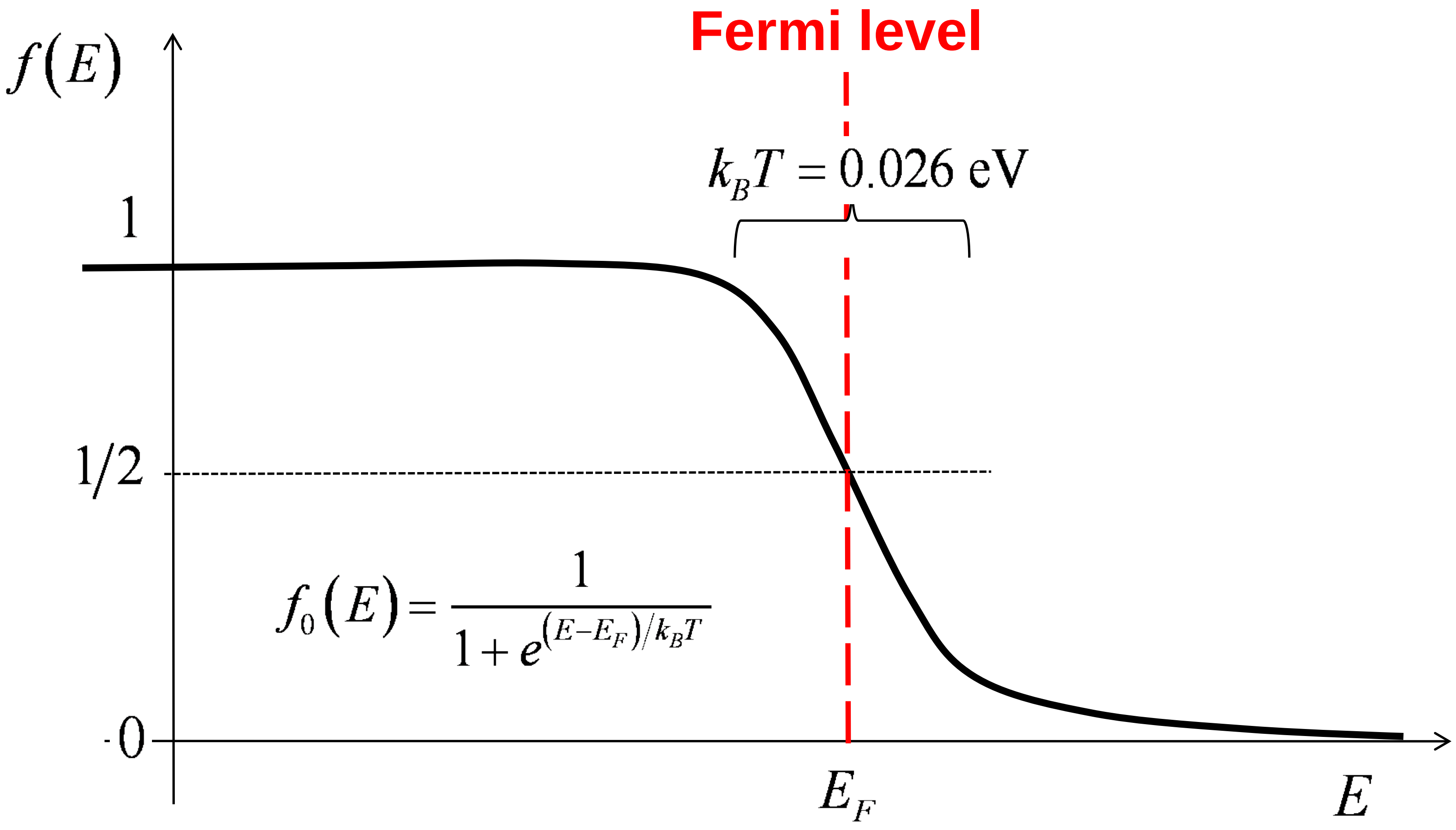
$$f_0(E) = \frac{1}{1+e^{(E-E_F)/k_BT}}$$

Fermi function

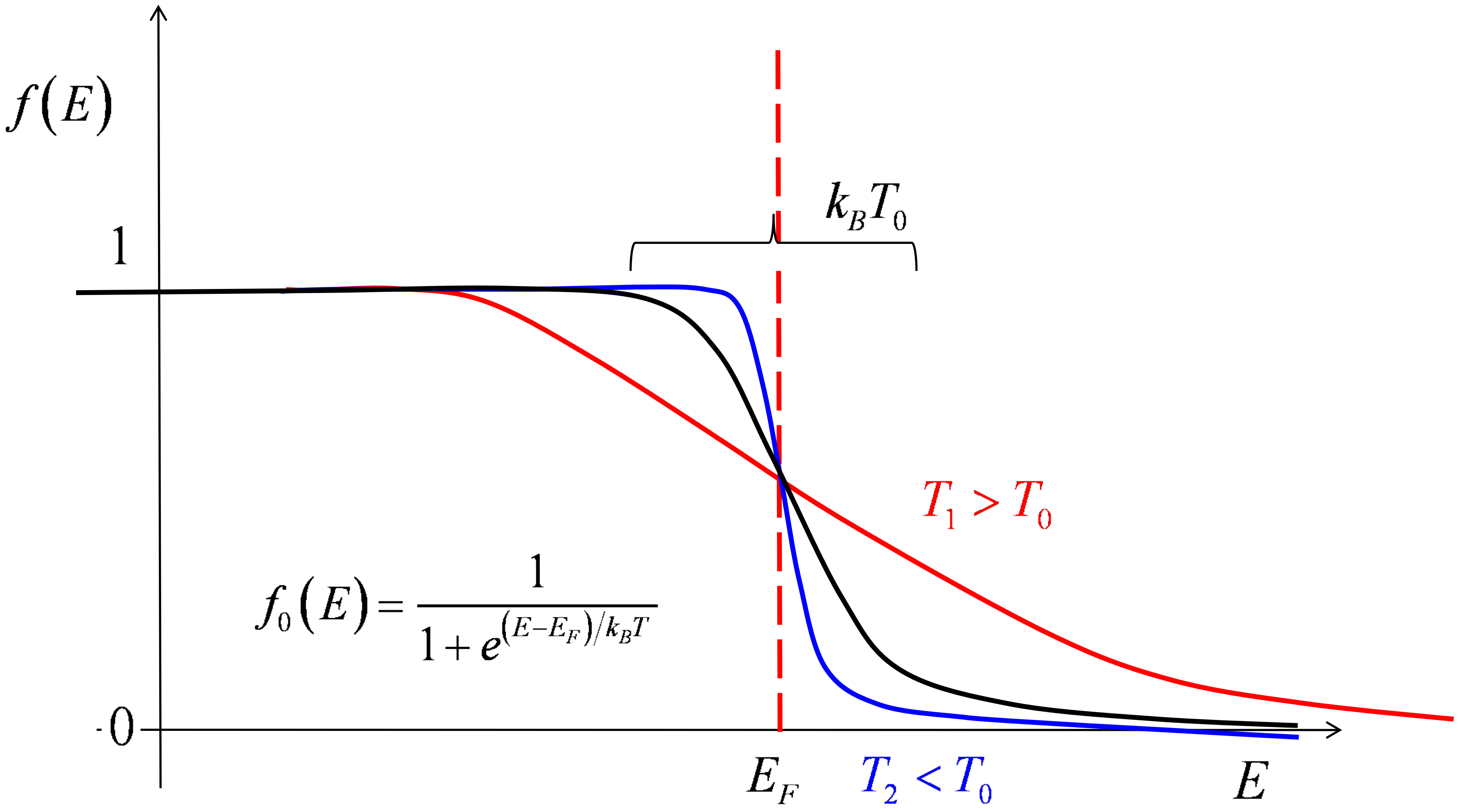
Probability that a state at energy, *E*, is occupied in equilibrium.



More about the Fermi function

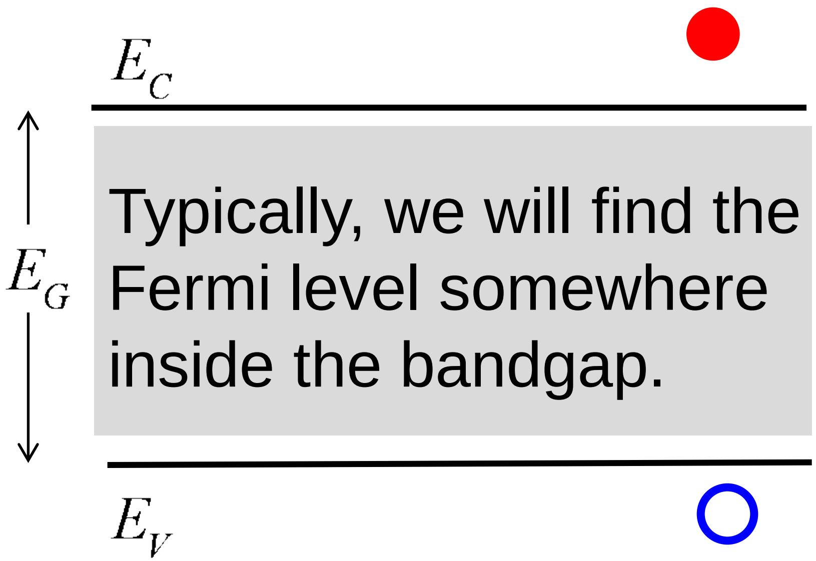


Effect of temperature



Electrons and holes

These states are way above the Fermi level.

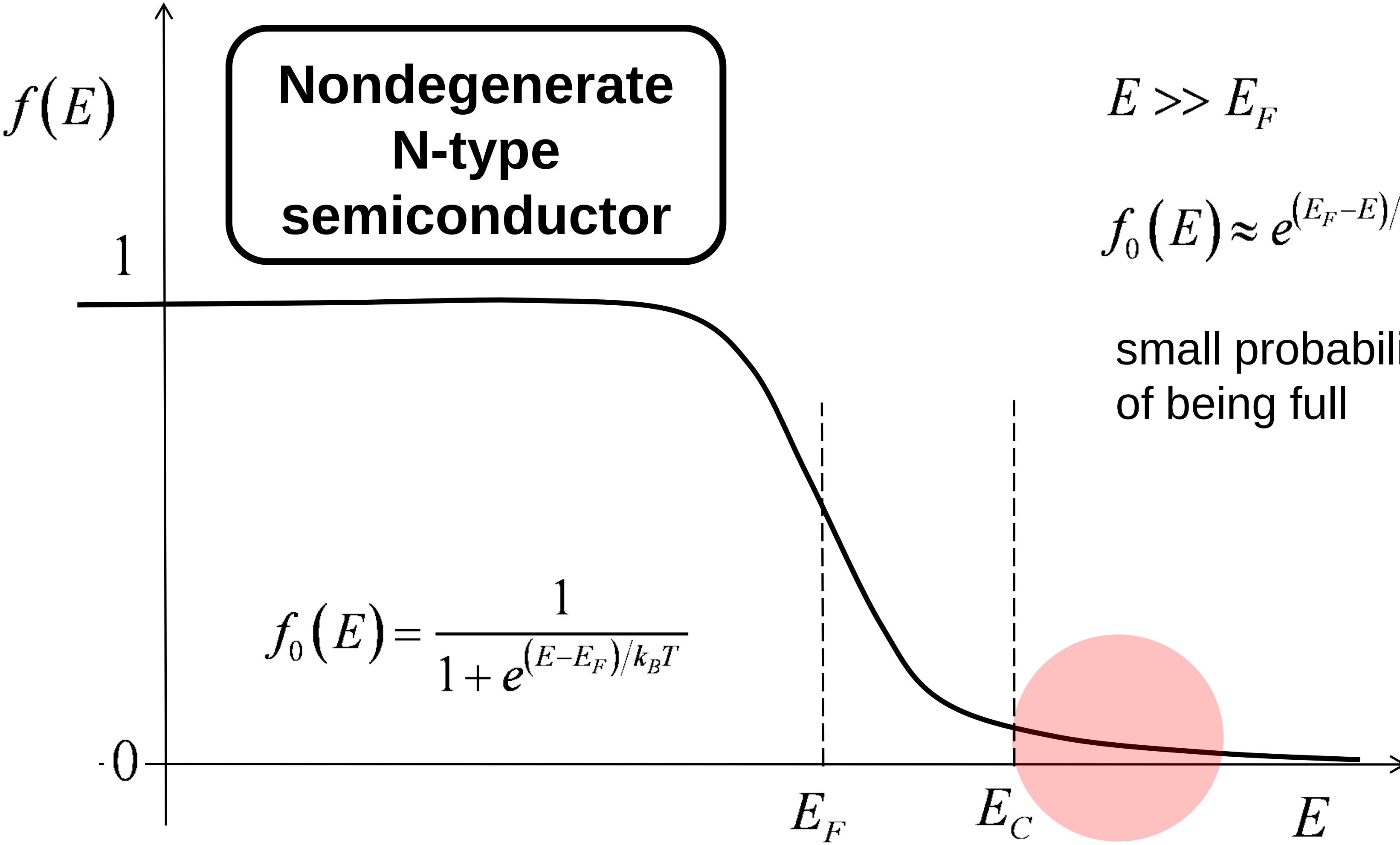


← A few states near E_C may be occupied.

← A few states near E_V may be empty.

These states are way below the Fermi level.

Conduction band



$E >> E_F$

$f_0(E) \approx e^{(E_F - E)/k_B T}$

small probability of being full

Valence band

small probability
of being empty

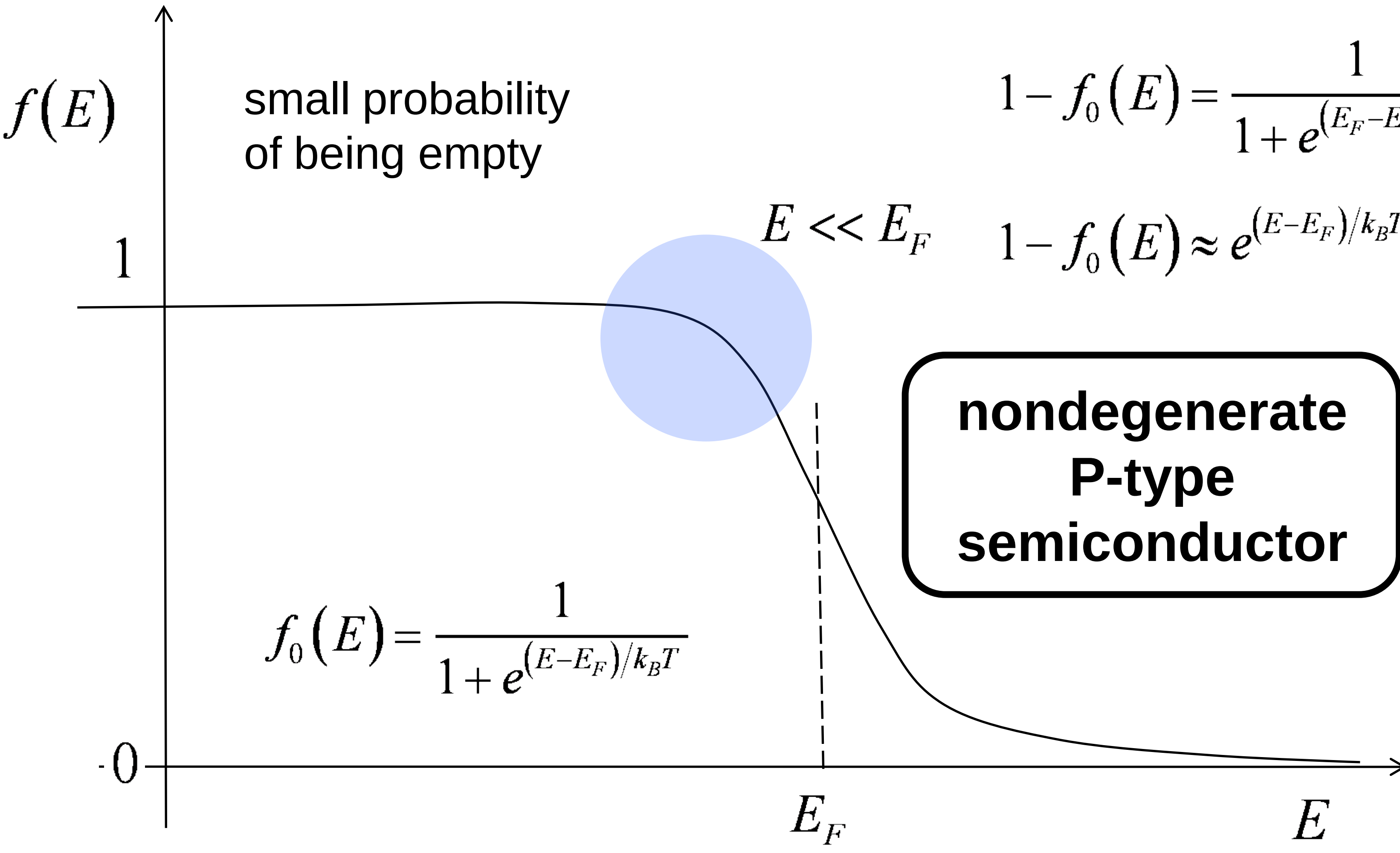
$$1 - f_0(E) = \frac{1}{1 + e^{(E_F - E)/k_B T}}$$

$E << E_F$

$$1 - f_0(E) \approx e^{(E - E_F)/k_B T}$$

nondegenerate
P-type
semiconductor

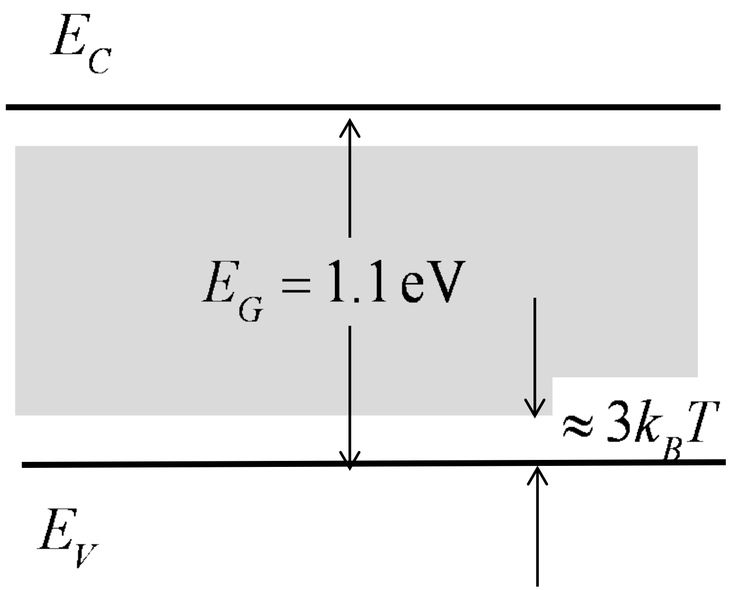
$$f_0(E) = \frac{1}{1 + e^{(E - E_F)/k_B T}}$$



Nondegenerate semiconductors

$$f_0\left(E_C\right) = \frac{1}{1 + e^{\left(E_C - E_F\right)/k_B T}}$$

$$f_0\left(E_C\right) \approx e^{\left(E_F - E_C\right)/k_B T}$$

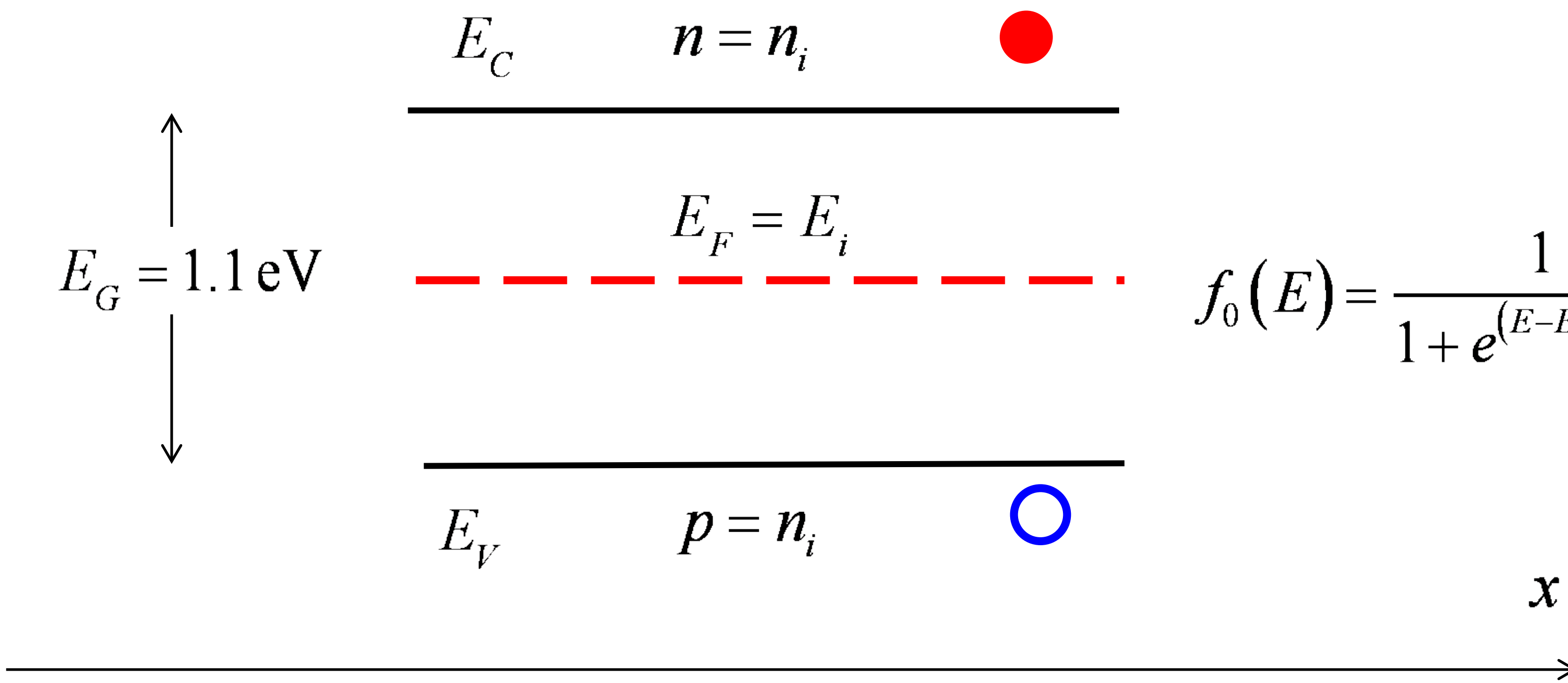


In a nondegenerate semiconductor, the Fermi level does not get too close to the band edges.

$$f_0\left(E_V\right) = \frac{1}{1 + e^{\left(E_V - E_F\right)/k_B T}}$$

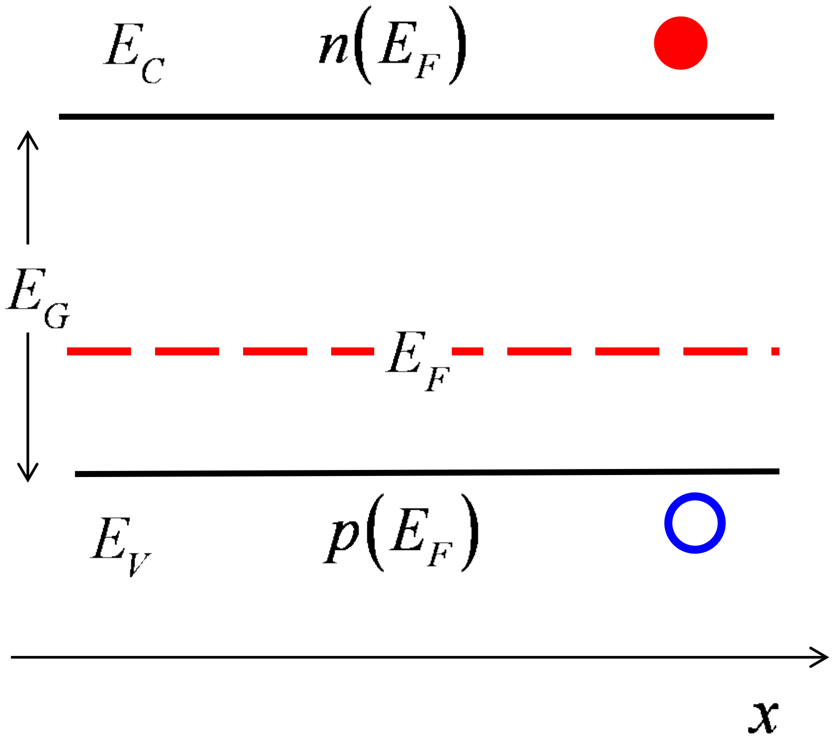
$$1 - f_0\left(E_V\right) \approx e^{\left(E_V - E_F\right)/k_B T}$$

Energy band diagram of an intrinsic semiconductor



$$f_0(E) = \frac{1}{1 + e^{(E - E_F)/k_B T}}$$

Energy band diagram and carrier densities



$$f_0(E) \approx e^{(E_F - E)/k_B T}$$

$$\boxed{n \propto e^{(E_F - E_C)/k_B T}}$$

$$1 - f_0(E) \approx e^{(E_V - E_F)/k_B T}$$

$$\boxed{p \propto e^{(E_V - E_F)/k_B T}}$$

Summary

The Fermi function gives the probability that a state (if it exists) is occupied in equilibrium.

$$\boxed{f_0(E) = \frac{1}{1+e^{(E-E_F)/k_BT}}}$$

(Fermi function)

The two key parameters in the Fermi function are the Fermi level and the temperature.