Current in semiconductor

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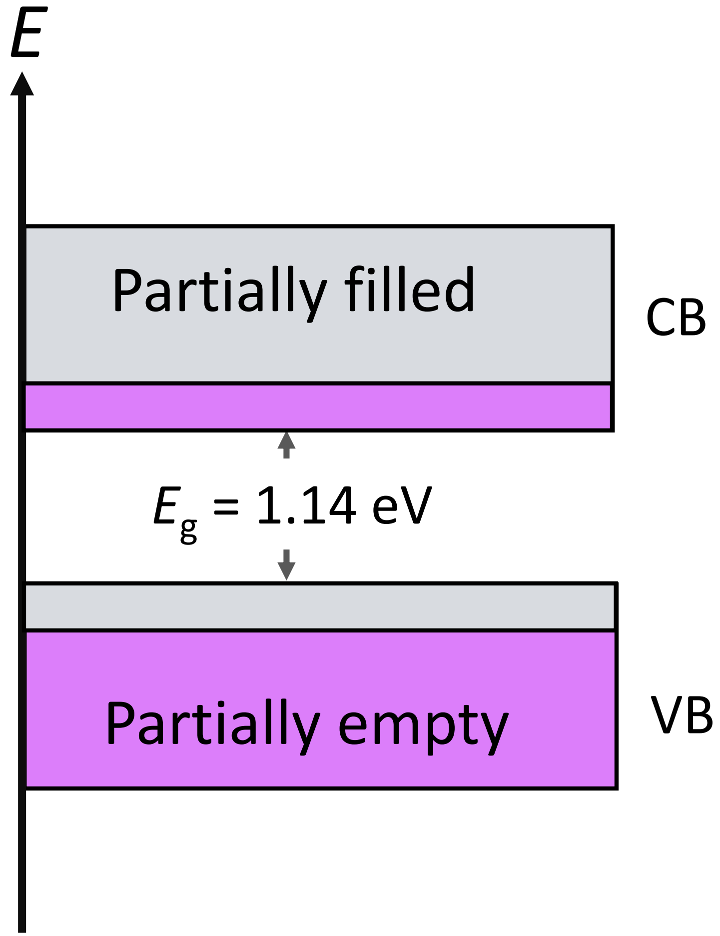
Current in semiconductor

Electric current is due to movement of charge carriers:

$$I = \sum_i q v_i$$

Semiconductor has:

- partially filled CB
- partially empty VB

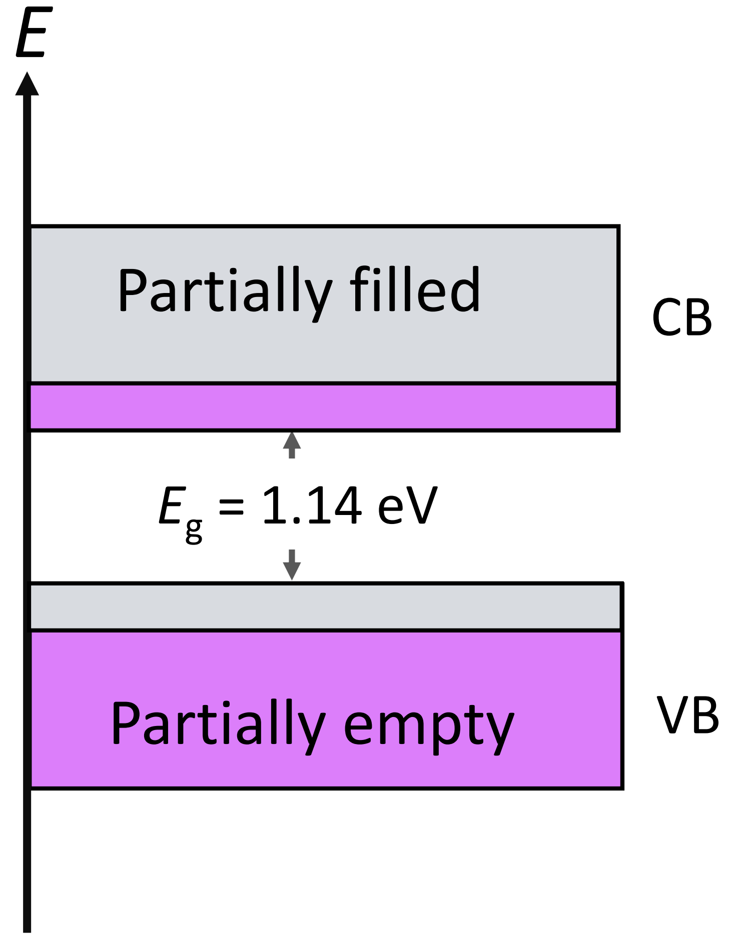


Current in semiconductor

Conduction band – almost empty, relatively small number of electrons move and conduct electricity

$$I_{\mathrm{CB}} = \sum_{\substack{\text{all electrons} \\ \text{in CB}}} (-q) v_i$$

$$q = 1.6 \times 10^{-19}\ \mathrm{C}$$

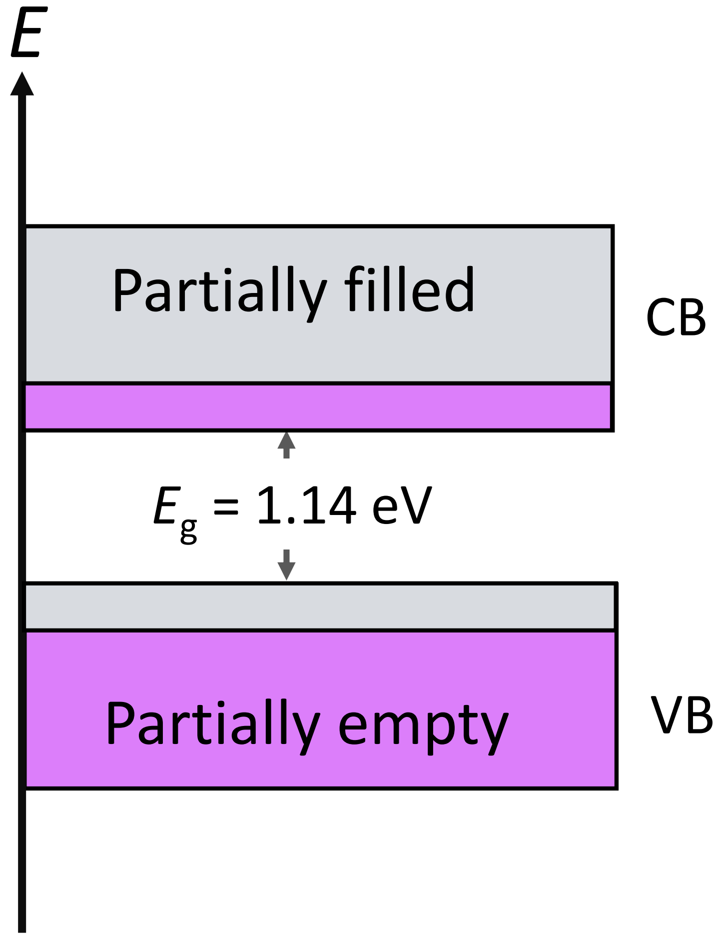


Current in semiconductor

Valance band – almost full, very large small number of electrons move and conduct electricity

$$I_{\mathrm{VB}} = \sum_{\substack{\text{filled ststes} \\ \text{in VB}}} (-q)v_i$$

Simpler description is to treat the relatively small number of empty states as positively charged particles called Hole.



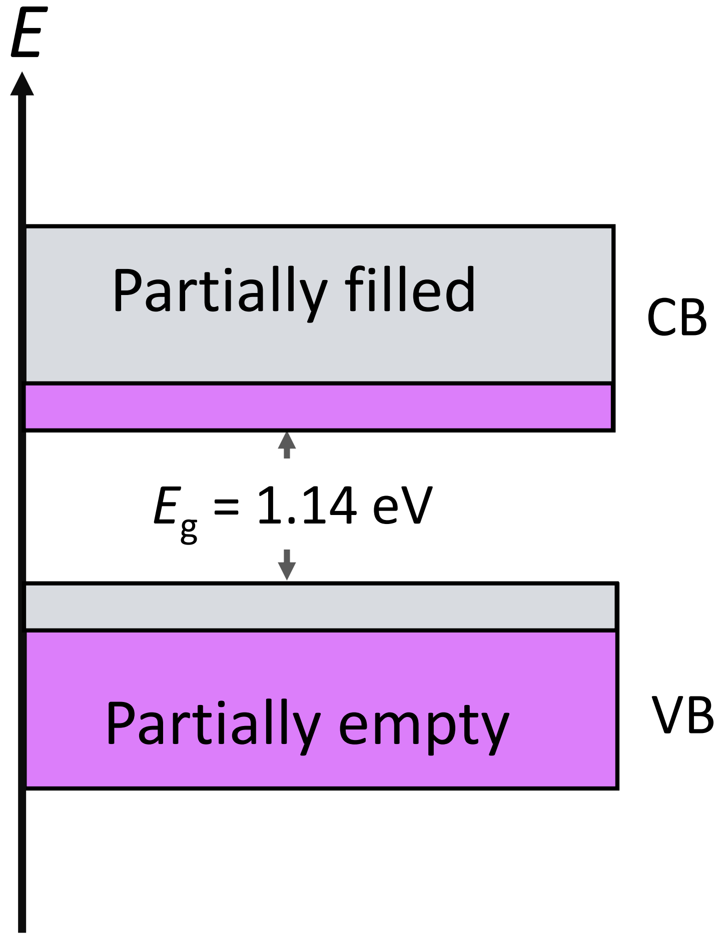
Current in semiconductor

Valance band:

$$I_{\mathrm{VB}} = \sum_{\substack{\text{filled ststes} \\ \text{in VB}}} (-q)v_i$$

$$= \sum_{\substack{\text{all} \\ \text{states}}} (-q)v_i - \sum_{\substack{\text{empty} \\ \text{states}}} (-q)v_i$$

$$= \sum_{\substack{\text{empty} \\ \text{states}}} (+q)v_i$$



Current in semiconductor

- Any motion of free carriers leads to a current.
- In a semiconductor, there are two types of carriers:
  - Electron and hole
- Carrier motion may be caused by
  - Electric field : drift current
  - Non-uniform carrier concentration: diffusion
- Assume carriers move at an average velocity of *v* then the current is given by

$$I = \frac{Q}{t} = \frac{Q}{L/v};$$

$$J = \frac{I}{A} = \frac{Q}{AL}v = \rho \mathrm{v} = -qnv$$

Current in semiconductor

- In order to know how much current flows in a semiconductor, we need to know:
  - How many carriers are there in each band?
  - How fast are the moving?

- To answer the first question, we need to know
  - How many available states are there in the conduction band?
  - What is the probability to find an electron in a given state?

Current in semiconductor

- How many available states are there in the conduction band?

  Density of states

- What is the probability to find an electron in a given state?

  Fermi-Dirac probability function

Density of states

- Energy bands: A number of closely-spaced energy levels

- Density of states, $g(E)$:

    - $g(E)$ is the number of states per unit volume per energy

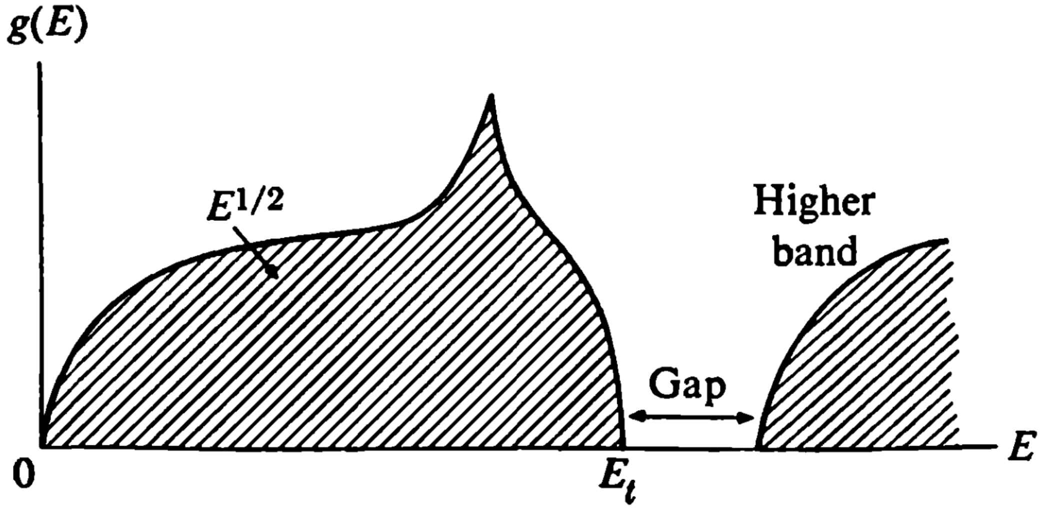
    - $g(E)$ dE is the number of states per unit volume between an infinitesimal energy range between E and dE

$$\boxed{g(E) \equiv \frac{\text{number of states in } \Delta E}{\Delta E \times \text{volume}}}$$

Density of states

$$g(E) = \frac{1}{2\pi^2}\left(\frac{2m^*}{\hbar^2}\right)^{3/2} E^{1/2}$$

m^* is the effective mass



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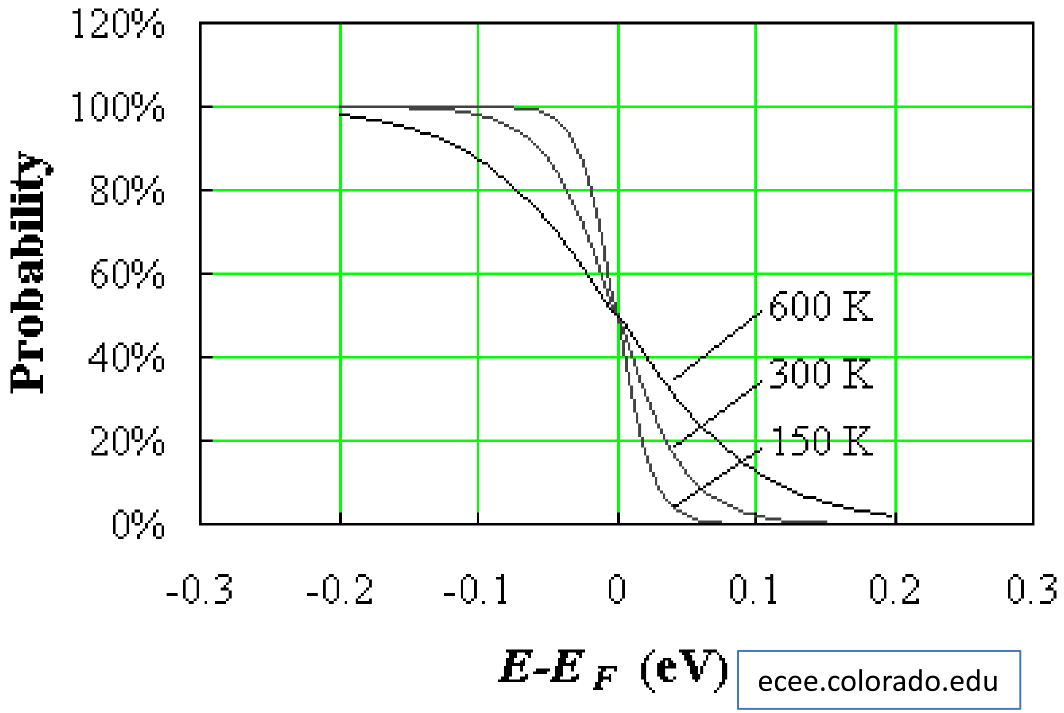
Fermi-Dirac probability function

The Fermi-Dirac distribution *f* gives the probability that an orbital at energy *E* will be occupied by an ideal electron in thermal equilibrium.

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

E_F is the Fermi-energy



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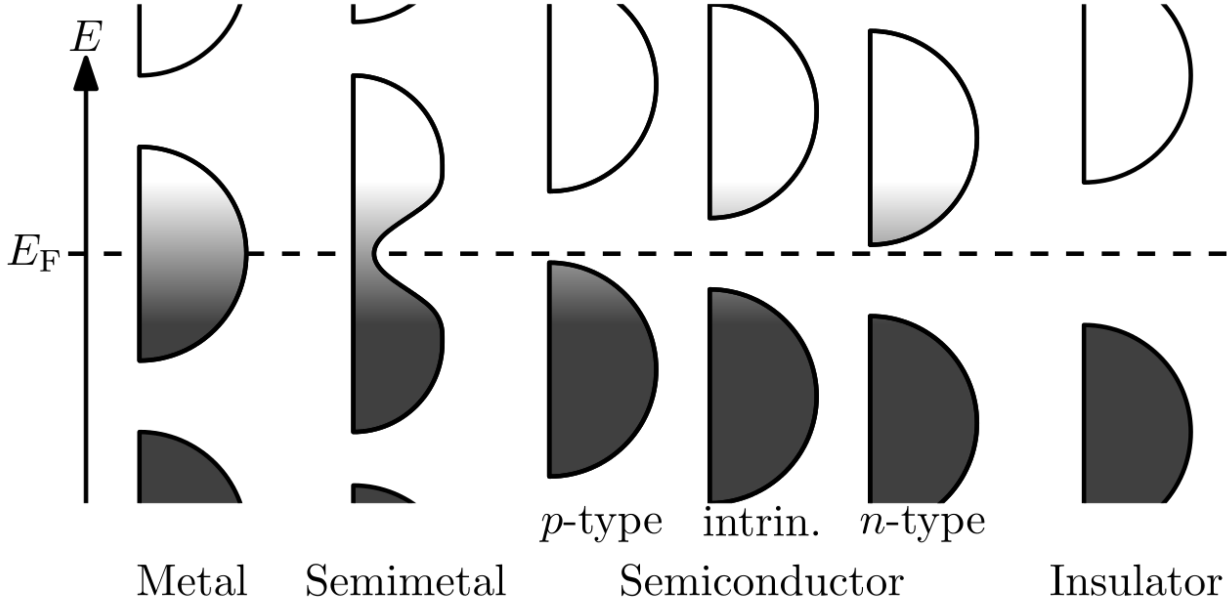
Electron Concentration

The electron concentration *n* in thermal nonequilibrium is expressed as

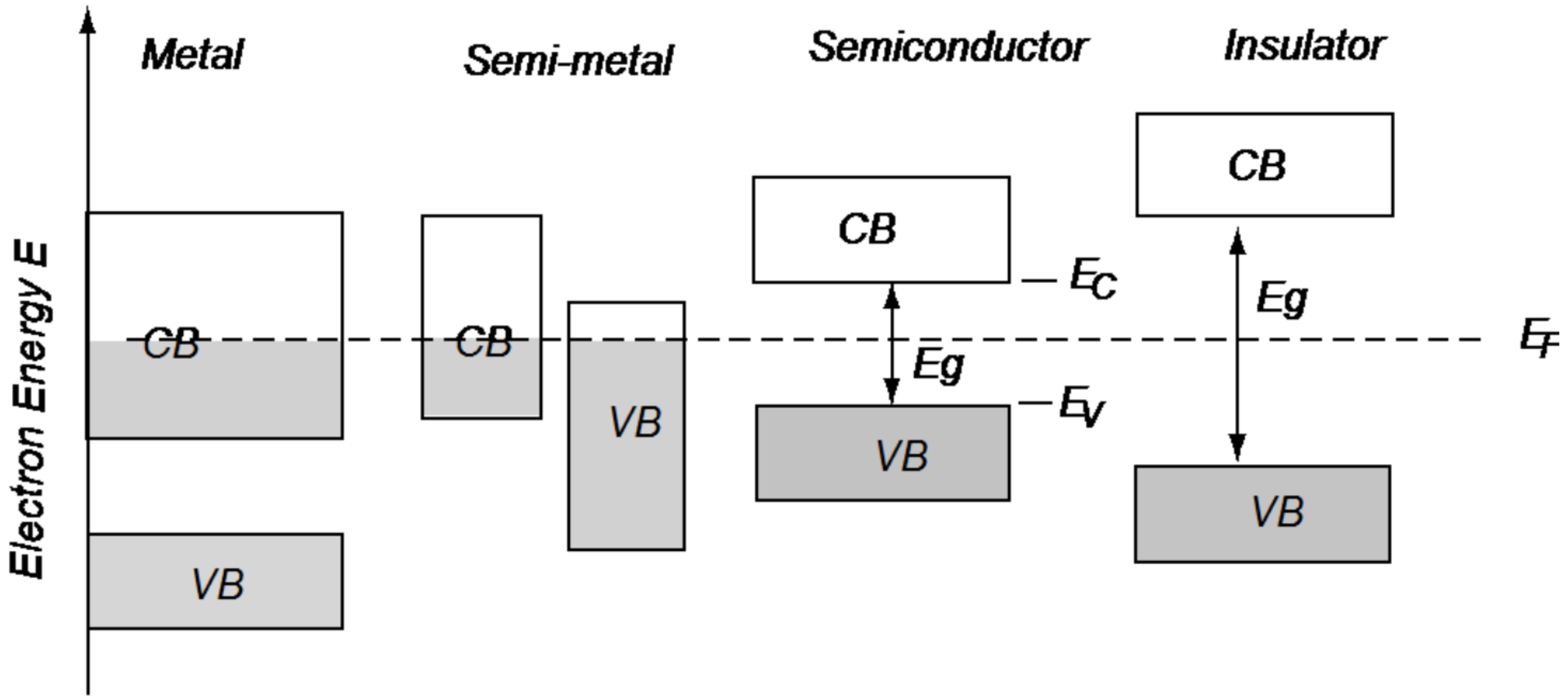
$$\boxed{n = \int_0^{\infty} g(E) f(E)\, \mathrm{d}E}$$

Fermi energy

Fermi energy is often defined as the highest occupied energy level of a material at absolute zero temperature. In other words, all electrons in a body occupy energy states at or below that body's Fermi energy at 0 K.

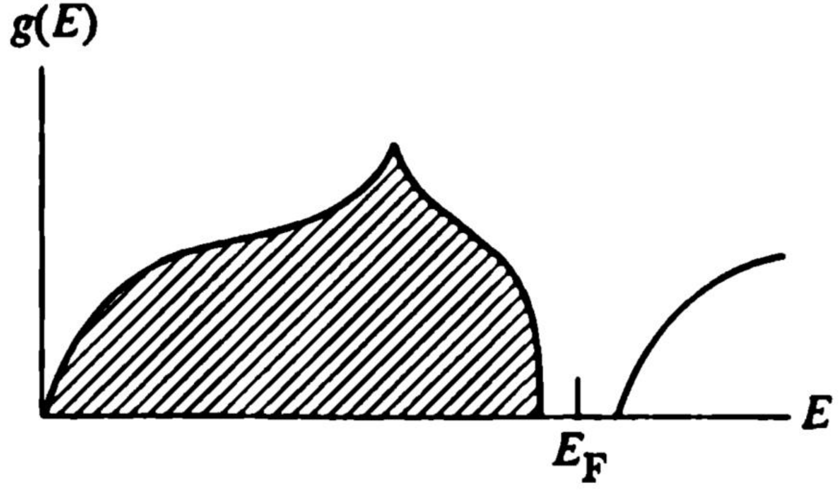


Energy level diagrams



Fermi energy in an insulator

$$n = \int_0^\infty g(E) f(E)\, \mathrm{d}E$$



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$$n = \int_0^{E_F} g(E) \mathrm{d}E$$

$$E_F = \frac{\hbar^2}{2m^*} \left(3\pi^2 n\right)^{2/3}$$

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