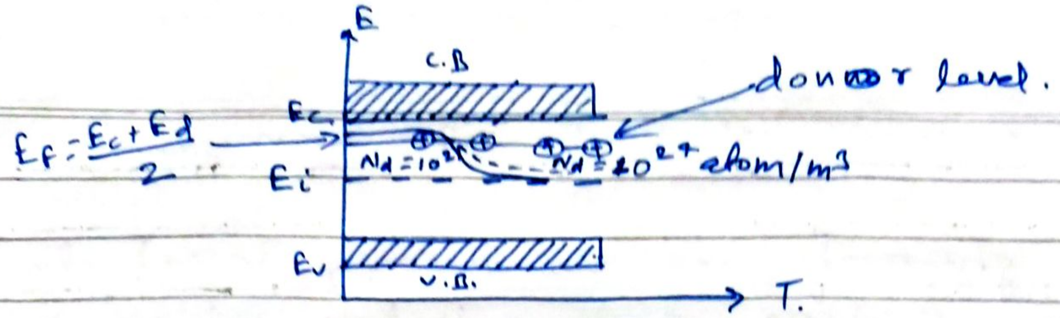
Carrier concentration in N-type semiconductors :

In the given figure the energy level diagram of an n-type semiconductor, where E_d is the donor energy level and ~~Nd~~ N_d is the donor concentration of the material

At very low temperature all donor levels are filled with the electrons and with the increase in temperature more and more donor atoms get ionized. The released electrons from the donors increase the concentration of the electrons in the conduction band.
Neglecting the concentration of thermally generated holes in the valence band
$n = N_d^+$ where N_d^+ is the concentration of donors.



The density of electron in the conduction is given by eq^n.

$$n = 2\left(\frac{2\pi m_e^* KT}{h^2}\right)^{3/2} e^{-(E_c - E_F)/KT}.$$

or $$n = 2\left(\frac{2\pi m_e^* KT}{h^2}\right) e^{(E_F - E_c)/KT}.$$

If the fermi level E_F lies more than a few KT above the ~~down~~ donor level E_d then the density of ionized donors is given by

$$N_d\left[1 - F(E_d)\right] \cong \cancel{N_d e} \; \cancel{N_d e^{(E_d - E_F)}} \; \cancel{N_d e} \; N_d e^{(E_d - E_F)/KT}.$$

If the fermi level E_F lies more ~~th~~. then the density of ionized donors is given by

$$N_d\left[1 - f(E_d)\right] \simeq N_d e^{(E_d - E_F)/KT} \qquad (1)$$

at very low temparatures the electron-hole pairs are not generated due to the breakage of covalent bonds.
Then the number of electrons

in the conduction band must be equal to the number of ionized donors in donor level E_d i.e.

$n = N_d^+$, N_d^+ is the concentration of ionized donors.

$$\therefore\ 2\left(\frac{2\pi m^* kT}{h^2}\right) e^{(E_f - E_c)/kT} = N_d\, e^{(E_d - E_f)/kT}$$

Taking logarithm on both sides of the above eqn we get after rearranging

$$\left(\frac{(E_f - E_c)}{kT}\right) - \left(\frac{E_d - E_f}{kT}\right) = \ln N_d - \ln 2\left(\frac{2\pi m_c^* kT}{h^2}\right)^{3/2}$$

or, $$2E_f - (E_d + E_c) = kT \ln\left[\frac{N_d}{2\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2}}\right]$$

or, $$E_f = \left(\frac{E_d + E_c}{2}\right) + \frac{kT}{2}\ln\left(\frac{N_d}{2\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2}}\right)$$

— (2)

At $T = 0\,K$

$$E_F = \frac{E_d + E_c}{2} \quad \text{--- (3).}$$

Thus at $0\,K$ the fermi level E_F lies Exactly at the middle of the donor level E_d and the bottom level of the conduction band. i fig. given fig.