$$n = \frac{1}{V}\int_{E_C}^{\infty} g_C(E) f(E,T) dE, \tag{1}$$

$$p = \frac{1}{V}\int_{-\infty}^{E_V} g_V(E)[1 - f(E,T)] dE. \tag{2}$$

$$E = E_g + \frac{\hbar^2 k^2}{2m_e^*} \tag{3}$$

$$g_C(E)dE = \frac{V}{2\pi^2}\left(\frac{2m_e^*}{\hbar^2}\right)^{3/2}(E - E_g)^{1/2} dE. \tag{4}$$

$$E = -\frac{\hbar^2 k^2}{2m_h^*} \tag{5}$$

$$g_V(E)dE = \frac{V}{2\pi^2}\left(\frac{2m_h^*}{\hbar^2}\right)^{3/2}(-E)^{1/2} dE. \tag{6}$$

$$f(E,T) = \frac{1}{e^{(E-\mu)/k_B T} + 1} \approx e^{-(E-\mu)/k_B T} \tag{7}$$

$$1 - f(E,T) = 1 - \frac{1}{e^{(E-\mu)/k_B T} + 1} \approx e^{(E-\mu)/k_B T} \tag{8}$$

$$n = \frac{1}{V}\int_{E_g}^{\infty} \frac{V}{2\pi^2}\left(\frac{2m_e^*}{\hbar^2}\right)^{3/2}(E - E_g)^{1/2} e^{-(E-\mu)/k_B T} dE = \frac{(2m_e^*)^{3/2}}{2\pi^2\hbar^3} e^{\mu/k_B T}\int_{E_g}^{\infty}(E - E_g)^{1/2} e^{-E/k_B T} dE \tag{9}$$

$$n = \frac{(2m_e^*)^{3/2}}{2\pi^2\hbar^3}(k_B T)^{3/2} e^{-(E_g-\mu)/k_B T}\int_0^{\infty} X_g^{1/2} e^{-X_g} dX_g. \tag{10}$$

$$n = 2\left(\frac{2\pi m_e^* k_B T}{h^2}\right)^{3/2} e^{-(E_g-\mu)/k_B T} = N_{\text{eff}}^C e^{-(E_g-\mu)/k_B T}, \tag{11}$$

$$p = 2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{3/2} e^{-\mu/k_B T} = N_{\text{eff}}^V e^{-\mu/k_B T}. \tag{12}$$

$$np = 4\left(\frac{k_B T}{2\pi\hbar^2}\right)^3 (m_e^* m_h^*)^{3/2} e^{-E_g/k_B T}, \tag{13}$$

$$n_i = p_i = 2\left(\frac{k_B T}{2\pi\hbar^2}\right)^{3/2} (m_e^* m_h^*)^{3/4} e^{-E_g/2k_B T}. \tag{14}$$

$$\mu = \frac{E_g}{2} + \frac{3}{4} k_B T \ln\left(\frac{m_h^*}{m_e^*}\right). \tag{15}$$

$$\omega_c = \frac{Be}{m_e^*} \tag{16}$$

$$E_n = -\frac{m_e e^4}{8\epsilon_0^2 h^2}\frac{1}{n^2}. \tag{17}$$

$$a_0 = \frac{4\pi\epsilon_0\hbar^2}{m_e e^2} \tag{18}$$

$$\sigma = e(n\mu_e + p\mu_h), \tag{19}$$

$$\frac{d^2U}{dx^2} = -\frac{\rho}{\epsilon\epsilon_0} \tag{20}$$

$$\left.\frac{dU}{dx}\right|_{x=-d_p,d_n} = 0. \tag{21}$$

$$\Delta U = \frac{e}{2\epsilon\epsilon_0}\left(N_d d_n^2 + N_a d_p^2\right). \tag{22}$$

$$d_p = \left(\frac{\Delta U 2\epsilon\epsilon_0}{eN_a}\frac{N_d}{N_a+N_d}\right)^{1/2}; \qquad d_n = \left(\frac{\Delta U 2\epsilon\epsilon_0}{eN_d}\frac{N_a}{N_a+N_d}\right)^{1/2}. \tag{23}$$

$$n_p = N_c e^{(\mu - E_g - e\Delta U)/k_B T}; \qquad p_p = N_v e^{(e\Delta U - \mu)/k_B T} \tag{24}$$

$$n_n = N_c e^{(\mu - E_g)/k_B T}; \qquad p_n = N_v e^{-\mu/k_B T} \tag{25}$$

$$|I_{\text{diffusion}}| = |I_{\text{drift}}| = |I_0| = Ce^{(\mu - E_g - e\Delta U)/k_B T}, \tag{26}$$

$$|I_{\text{diffusion}}| = Ce^{((\mu+eV) - E_g - e\Delta U)/k_B T}. \tag{27}$$

$$I = I_{\text{diffusion}} - I_{\text{drift}} = I_0\left(e^{eV/k_B T} - 1\right). \tag{28}$$

$$|I_{\text{diffusion}}| = Ce^{((\mu-eV) - E_g - e\Delta U)/k_B T}. \tag{29}$$

$$I = I_{\text{diffusion}} - I_{\text{drift}} = I_0\left(e^{-eV/k_B T} - 1\right). \tag{30}$$