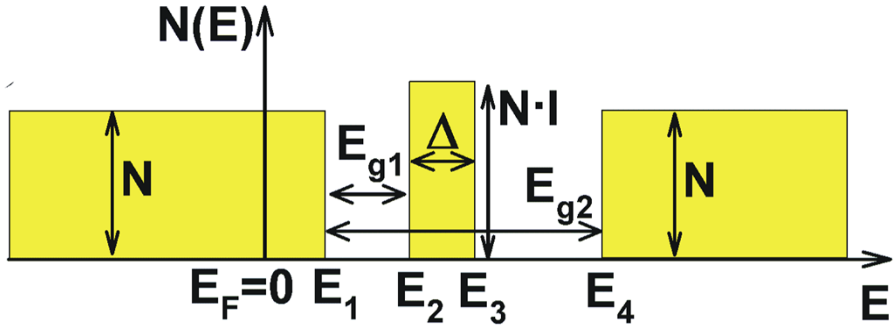

$$N(E)=\begin{cases} N & E\le E_1 \\ 0 & E_1<E<E_2 \\ N\cdot I & E_2\le E\le E_3 \\ 0 & E_3<E<E_4 \\ N & E\ge E_4 \end{cases}\qquad \begin{aligned} E_2&=E_1+E_{g1}\\ E_3&=E_1+E_{g1}+\Delta\\ E_4&=E_1+E_{g2}\end{aligned}\qquad f(E)=\left[1+\exp\left(\frac{E-E_F}{k_BT}\right)\right]^{-1}$$

$$n_e(T)=\int_{E_F=0}^{\infty}N(E)f(E)dE=N\left[\int_{E_F=0}^{E_1}f(E)dE+\int_{E_4}^{\infty}f(E)dE+I\int_{E_2}^{E_3}f(E)dE\right]$$

$$=N\left[\begin{aligned}&\left[-E_{g2}-k_BT\ln\left(\exp\left(\frac{E_1}{k_BT}\right)+1\right)+k_BT\ln 2+k_BT\ln\left(\exp\left(\frac{E_1+E_{g2}}{k_BT}\right)+1\right)\right]\\ &+I\left[\Delta+k_BT\ln\left(\exp\left(\frac{E_1+E_{g1}}{k_BT}\right)+1\right)-k_BT\ln\left(\exp\left(\frac{E_1+E_{g1}+\Delta}{k_BT}\right)+1\right)\right]\end{aligned}\right]$$

$$n_h(T)=\int_{-\infty}^{E_F=0}N(E)\left(1-f(E)\right)dE=N\int_{-\infty}^{E_F=0}\left(1-f(E)\right)dE$$

$$=Nk_BT\ln 2$$

$$n_{ch}(T)=\sqrt{n_e(T)n_h(T)}+n_{ch}^0$$

$$\rho(T)=\frac{n_{ch}^0\left(\rho_0+\rho_{ph}(T)\right)}{n_{ch}(T)}$$