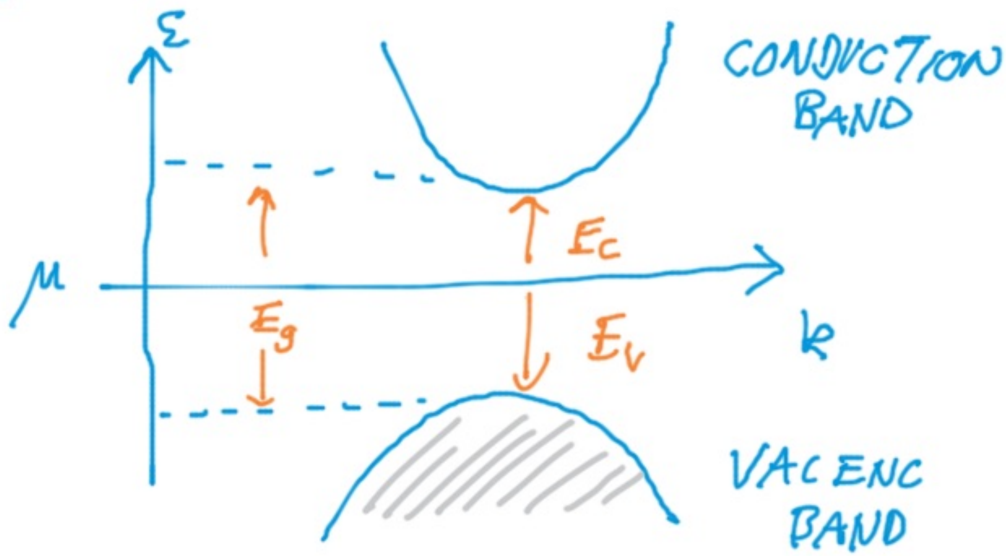
# SEMICONDUCTOR CARRIER CONCENTRATION




$$E_g = E_c + E_v$$

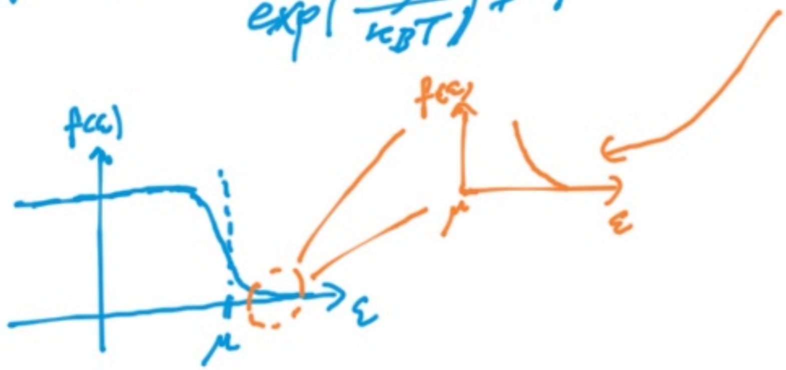
LET'S CONSIDER Ge THAT HAS $E_g = 0.66\,eV$.

FOR $T = 300K \longrightarrow E_g \gg k_B T$

$$\frac{E_g}{2} + \cancel{\mu} \gg k_B T$$

# FERMI DIRAC DISTRIBUTION

$$f(\varepsilon) = \frac{1}{\exp\left(\frac{\varepsilon-\mu}{k_BT}\right)+1} \approx \exp\left(+\frac{\mu-\varepsilon}{k_BT}\right) \equiv f_e(\varepsilon)$$




# CONDUCTION BAND DISPERSION


$$\varepsilon_k = E_c + \frac{\hbar^2 k^2}{2m_e}$$

## Electron mass notation

$m_0$ = free electron mass

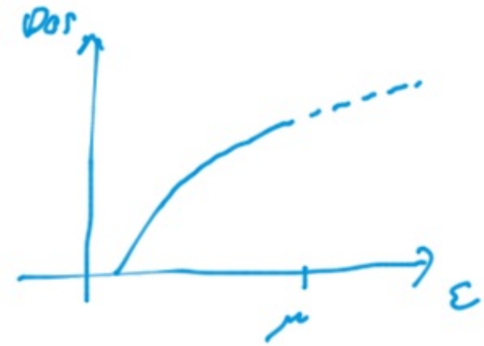
$m^*$ = effective electron mass

$m_e$ = conduction electron mass

$m_h$ = "hole" electron mass

## DENSITY-OF-STATES

$$D_c(\varepsilon) = \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar}\right)^{3/2}(\varepsilon-\varepsilon_c)^{1/2}$$




## CONCENTRATION-OF-CONDUCTION-ELECTRONS:

$$n = \int_{E_c}^{\infty} D_c(\varepsilon) f_\varepsilon(\varepsilon) = \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar}\right)^{3/2} \exp\left(\frac{\mu}{k_BT}\right)\int_{E_c}^{\infty}(\varepsilon-E_c)^{1/2}\exp\left(\frac{-\varepsilon}{k_BT}\right)d\varepsilon$$

NEW VAR.

$$x = \frac{\varepsilon-\varepsilon_c}{k_BT}$$

$$= \frac{(k_BT)^{3/2}}{2\pi^2}\left(\frac{2m_e}{\hbar}\right)^{3/2}\exp\left(\frac{\mu-E_c}{k_BT}\right)\int_0^{\infty}\sqrt{x}\,\exp(-x)\,dx$$

$$\frac{\varepsilon}{k_BT} = x + \frac{\varepsilon_c}{k_BT}$$

$$= 2\left(\frac{m_e\cdot k_BT}{2\pi\hbar^2}\right)^{3/2}\exp\left(\frac{\mu-E_c}{k_BT}\right)$$

$$\frac{d\varepsilon}{dx} = k_BT$$

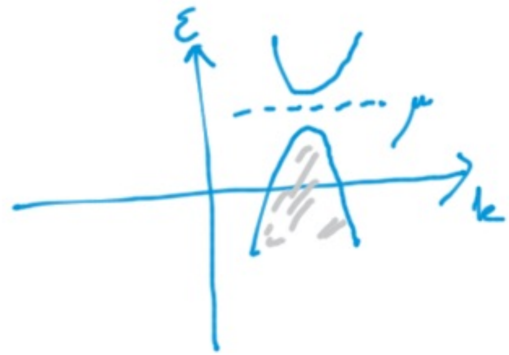
# CHARGE CARRIER DENSITY

$$n(T) = 2\left(\frac{m_e \cdot k_B T}{2\pi\hbar^2}\right)^{3/2} \exp\left(\frac{\mu - E_c}{k_B T}\right)$$

$$p(T) = 2\left(\frac{m_h \cdot k_B T}{2\pi\hbar^2}\right)^{3/2} \exp\left(\frac{E_v - \mu}{k_B T}\right)$$

$$n(T) \cdot p(T) = \frac{1}{2}(m_e m_h)^{3/2}\left(\frac{k_B T}{\pi\hbar^2}\right) \exp\left(\frac{-E_g}{k_B T}\right)$$

# CHEMICAL POTENTIAL




$$n = p \quad \Rightarrow \quad \frac{n(T)}{p(T)} = \left(\frac{m_e}{m_h}\right)^{3/2} \exp\left(\frac{+2\mu - (E_c + E_v)}{k_B T}\right) = 1$$

$$\Rightarrow \quad \log\left(\frac{m_h}{m_e}\right)^{3/2} = \frac{2\mu - (E_c + E_v)}{k_B T}$$

$$\Rightarrow \quad \mu = \frac{E_c + E_v}{2} + \frac{3}{4} k_B T \log\left(\frac{m_e}{m_h}\right)$$

## ESTIMATE $n(300K)$ FOR GERMANIUM

$E_g = 0.6\ eV$

$|\mu - E_c| = 0.3\ eV = 300\ meV$

$k_B T \approx 30\ meV$ @ 300 K

$m_e = 0.04\ m_0$ $m_0$ = free electron mass

$n = \frac{1}{2} \cdot 10^{17} \exp(-10) = 2.5 \cdot 10^{12}\ cm^{-3}$

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Unit cell $\approx 10\ \mathring{A}^3$

1 electron per 10,000 unit cells

$n = \frac{1}{10000} \frac{1}{10\ \mathring{A}^3} = 10^{-5} \cdot 10^{30}\ m^{-3} = 10^{+25}\ m^{-3} = 10^{+19}\ cm^{-3}$