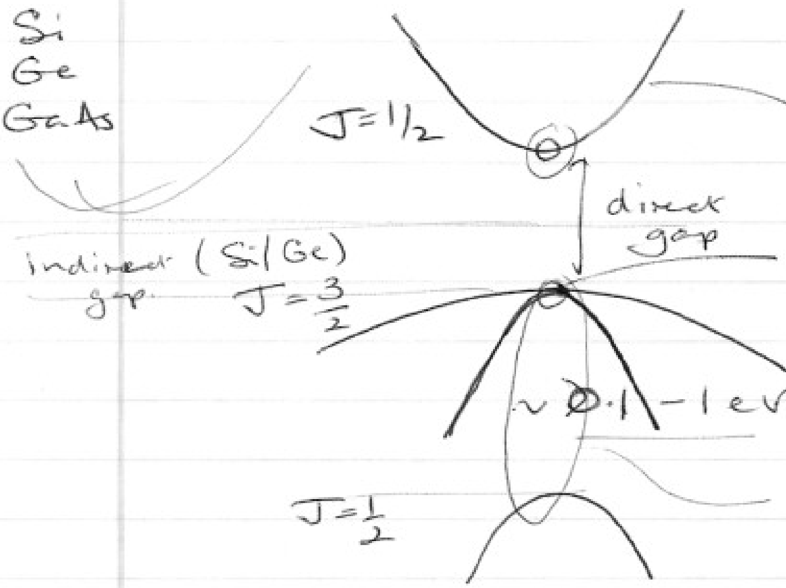
Semiconductors

Bands near $k=0$ $\Rightarrow$ $\psi_k(r) = e^{i\underline{k}\cdot\underline{r}} u_k(r)$

$k=0 \rightarrow$ same in every unit cell.

Si
Ge
GaAs



$\lambda \underline{L}\cdot\underline{S}$

$L=1,\ S=1/2$ (6 states)

$J=\frac{3}{2}$ $\qquad$ $J=1/2$

degen $2J+1$ $\qquad$ 4 $\qquad$ 2

- Si/Ge — indirect gap
  - optical absorption by phonon assisted process
- GaAs — strong optical activity
  - direct gap
  - dipole-active transition. $\Delta L = \pm 1$

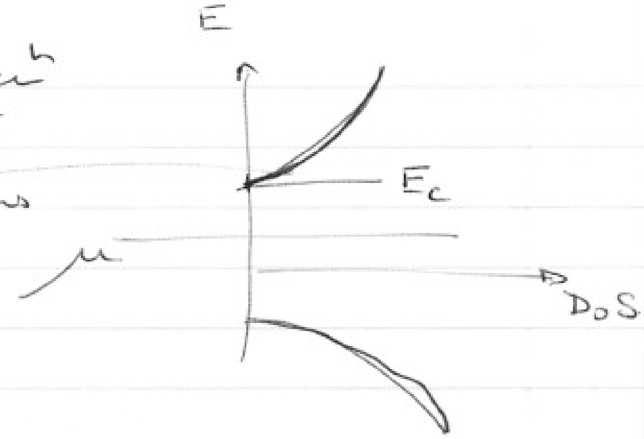
$$\langle \phi_c | e^{i\underline{q}\cdot\underline{r}} | \phi_v \rangle$$

$$= \langle \phi_c | 1 + i\underline{q}\cdot\underline{r} + \ldots | \phi_v \rangle \simeq i\underline{q}\cdot\langle \underset{S}{\phi_c} | \underline{r} | \underset{P}{\phi_v} \rangle$$

Intrinsic Carrier Concⁿ

Thermal occ of electrons

~~$f(E_c - \mu)$~~



$$n = \int_{E_c}^{\infty} dE\, \underbrace{g_c(E)}_{\propto (E-E_c)^{1/2}} \cdot f(E) \qquad f(E) \propto \frac{1}{e^{(E-\mu)/kT}+1} \simeq e^{-(E-\mu)/kT}$$

$$n \simeq \underbrace{2\left(\frac{m_e^* k_B T}{2\pi\hbar^2}\right)^{3/2}}_{\text{\# of states within energy} \sim kT \text{ of band edge}} e^{-\left(\frac{E_c-\mu}{kT}\right)}$$

$e^{-\left(\frac{E_c-\mu}{kT}\right)}$ ← Boltzmann factor

Holes: ?

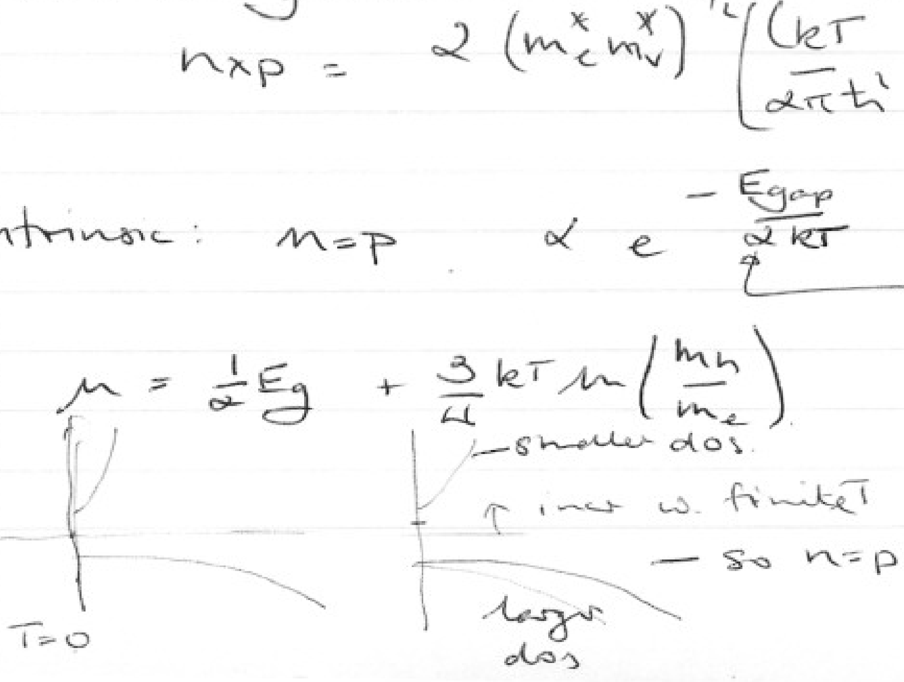
$$p = 2\left(\frac{m_v^* k_B T}{2\pi\hbar^2}\right)^{3/2} e^{-\left(\frac{\mu-E_v}{kT}\right)}$$

True in general:

$$n \times p = 2\left(m_c^* m_v^*\right)^{3/2} \left[\frac{kT}{2\pi\hbar^2}\right]^3 \underbrace{e^{-\frac{(E_c-E_v)}{kT}}}_{e^{-E_{gap}/kT}}$$

Intrinsic: $n = p \quad \propto e^{-\frac{E_{gap}}{2kT}}$ ← note the 2

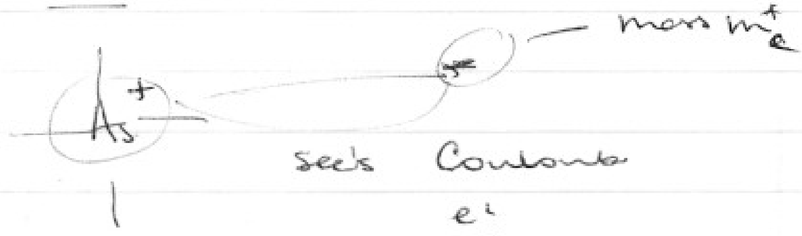
$$\mu = \frac{1}{2}E_g + \frac{3}{4}kT\ln\left(\frac{m_h}{m_e}\right)$$



Extrinsic Semicond.

Donors: As (group V) in Si

↘ adds 5 electrons → 1 extra



sees Coulomb

$$\frac{e^2}{4\pi\varepsilon\varepsilon_0 r} \qquad \varepsilon \sim 12$$

— just like H. but different binding

Rydberg. $\Delta \quad \frac{e^4 m_e^*}{2(4\pi\varepsilon\varepsilon_0\hbar^2)^2} \sim \frac{m^*/m}{\varepsilon^2} \times 13.6\,\text{eV}.$

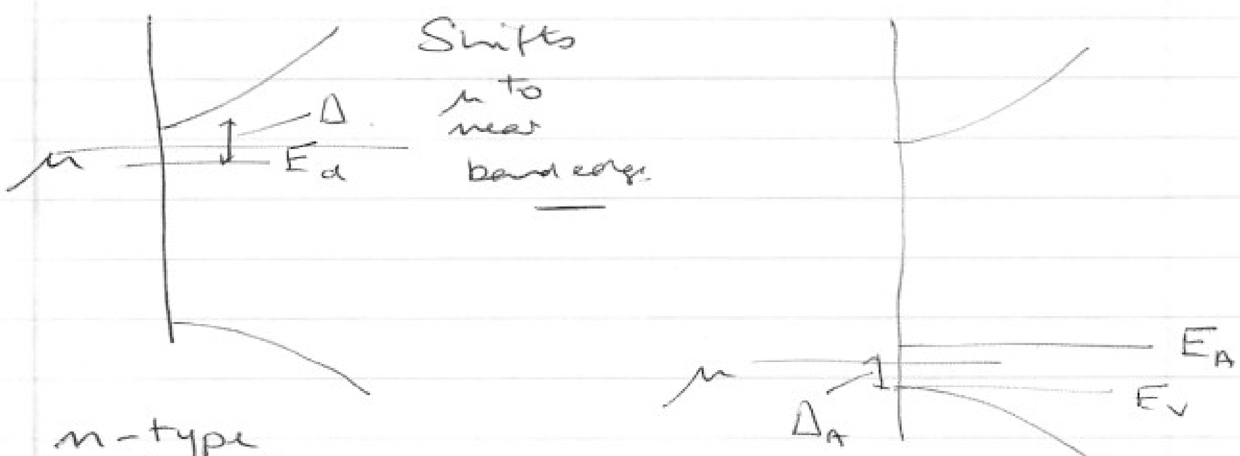
usually factor of $\sim 10^{-2} - 10^{-3}$.

Acceptor? B (group III) in Si.

adds 3 electrons when 4 expected

→ binds a hole.

— Binding energy may be ~ to kT.



n-type.

N.B.
np = const.

p-type

If $kT \ll \Delta_d$ (law of mass action)

$$n \simeq (n_c N_d)^{1/2} e^{-\Delta_d/2kT}$$

N_d ← donor density

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

$kT \gg \Delta_d$

$$n \sim N_d.$$

- Doping shifts chemical potential near
  Cond band (n-type)
  Val. band (p-type).
- If doping not too high, still always
  $np \propto e^{-E_{gap}/kT}$.

  — increase n, reduce p.
- $\mu \equiv$ of heterogeneous material
  $\mu =$ const. — basis of semiconductor devices.

  — but then $n(r)$, $p(r)$ not uniform

  $\Rightarrow$ electrostatic pot^l

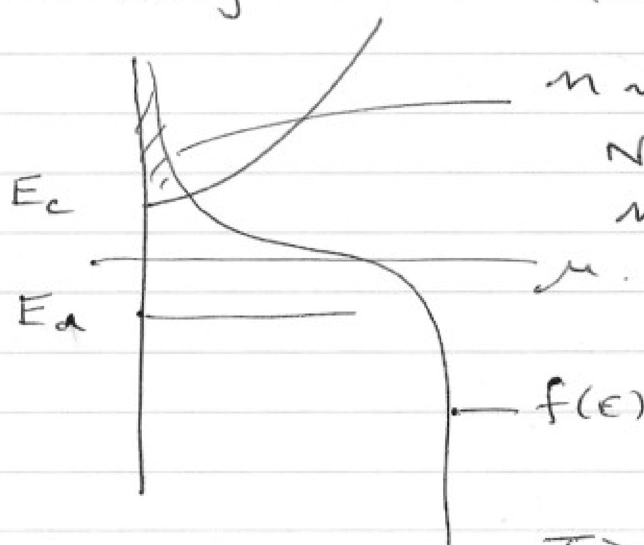
Semiconductor

Small energy. $\Rightarrow \Delta = \text{Rydberg} = \dfrac{13.6\,\text{eV} \times (m^*/m)}{\varepsilon^2}$

$\sim 10 - 100\ \text{meV}$.

Extrinsic

Donors only (low T)



$n \sim (N_d\, n_c)^{1/2}\, e^{-\frac{\Delta}{2kT}}$

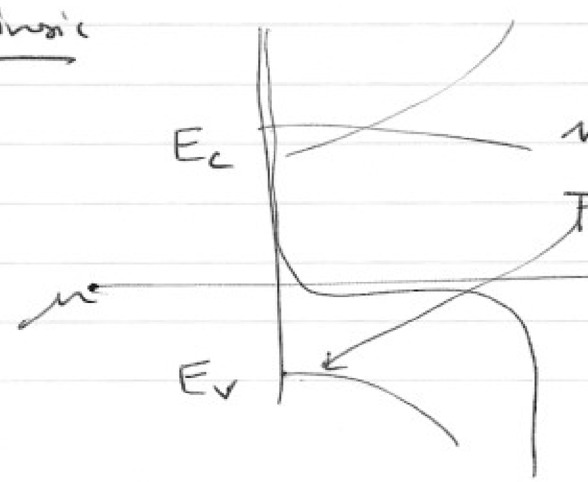
N_d = donor density

$n_c = 2\left(\dfrac{m^* kT}{2\pi\hbar^2}\right)^{3/2}$ — # density of states within kT of band edge.

$T \gtrsim \Delta$ $\boxed{n = N_d}$

or density high

Intrinsic



$n_i = n_c\, e^{-(E_c-\mu)/kT}$

$p_i = n_v\, e^{-(\mu-E_v)/kT}$

$n_i \cdot p_i = n_c n_v\, e^{-\frac{E_{gap}}{kT}}$ — indep of μ.