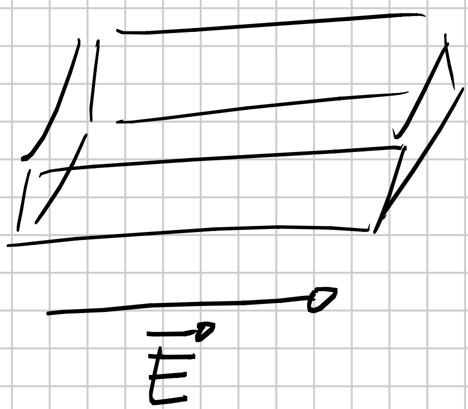
LECTURE #21

Note Title 11/26/2007

TRANSPORT PROPERTIES



$$\vec{J} = \sigma \vec{E}$$

σ CONDUCTIVITY

$$\vec{J} = -e n \langle \vec{v} \rangle = \boxed{\frac{n e^2 \tau}{m}} \vec{E}$$

τ AVERAGE DELAY BETWEEN 2 e-PHONON SCATTERING EVENTS

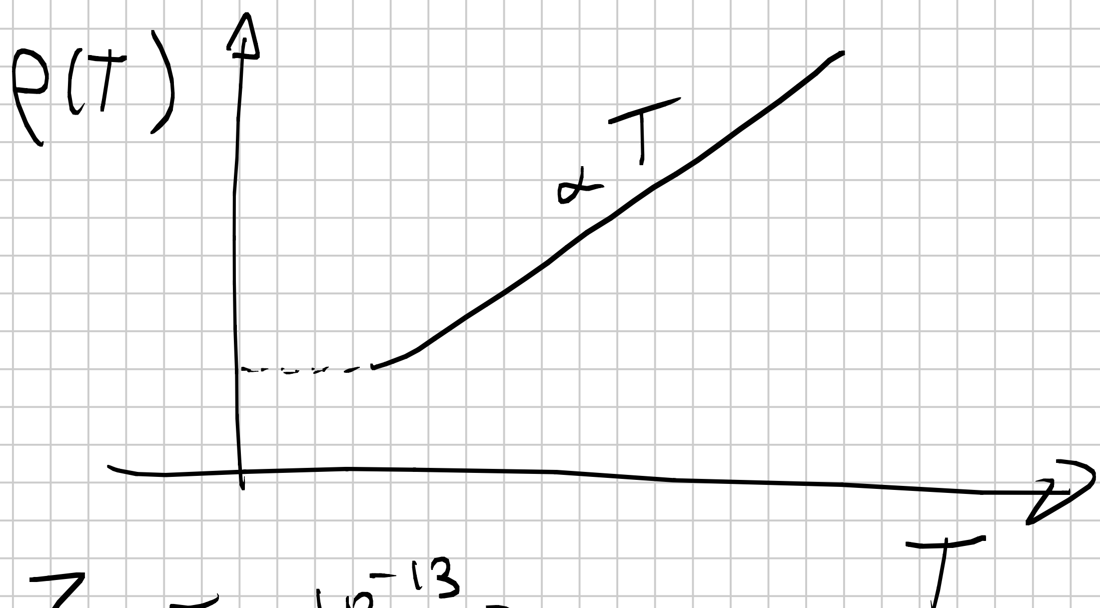
WHAT IS m?

CASE 1 METAL

$n \to$ DENSITY OF e^- AT THE FERMI SURFACE

$\frac{1}{\sigma} = \rho$ (RESISTIVITY)

$\rho \sim 10^{-6} - 10^{-3}\ \Omega\,\mathrm{cm}$



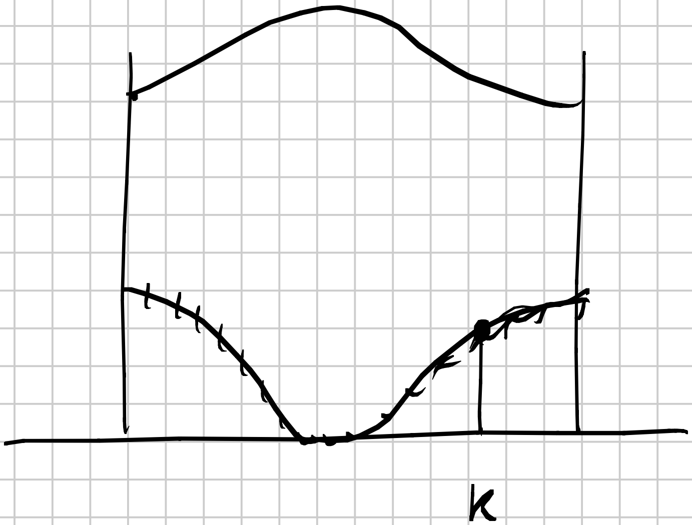
$\sigma \propto \tau \Rightarrow \rho \propto \frac{1}{\tau}$

$\frac{1}{\tau}$ RATE OF e-PHONON SCATT

$\propto n_{ph} \sim k_B T$

$\tau \sim 10^{-13}$ sec

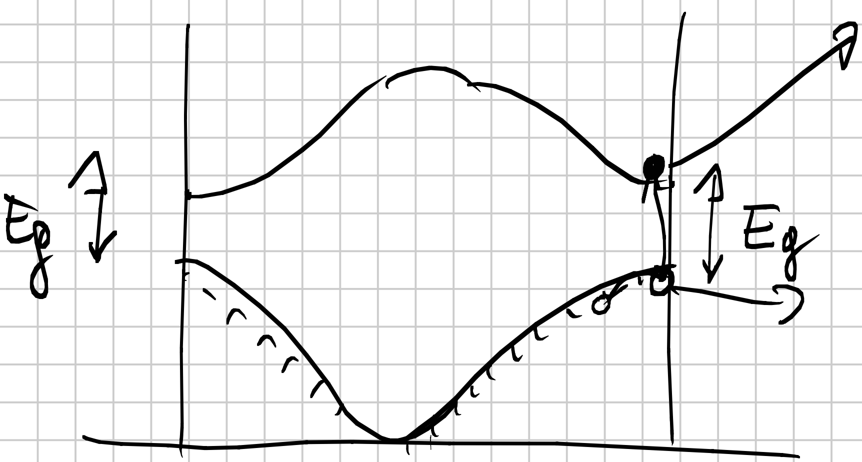
② INSULATOR



$n \sim 0 \qquad \sigma \sim 0$

$\rho \sim \infty \qquad \rho \sim 10^{22}\ \Omega\,\text{cm}$

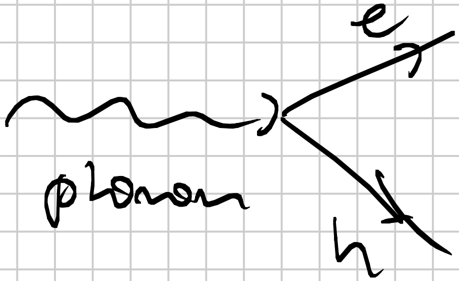
③ SEMICONDUCTORS



<u>conduction electron</u>

Hole

behaves as a positive charge



$$n \cdot p = c\, e^{-\frac{E_g}{k_B T}}$$

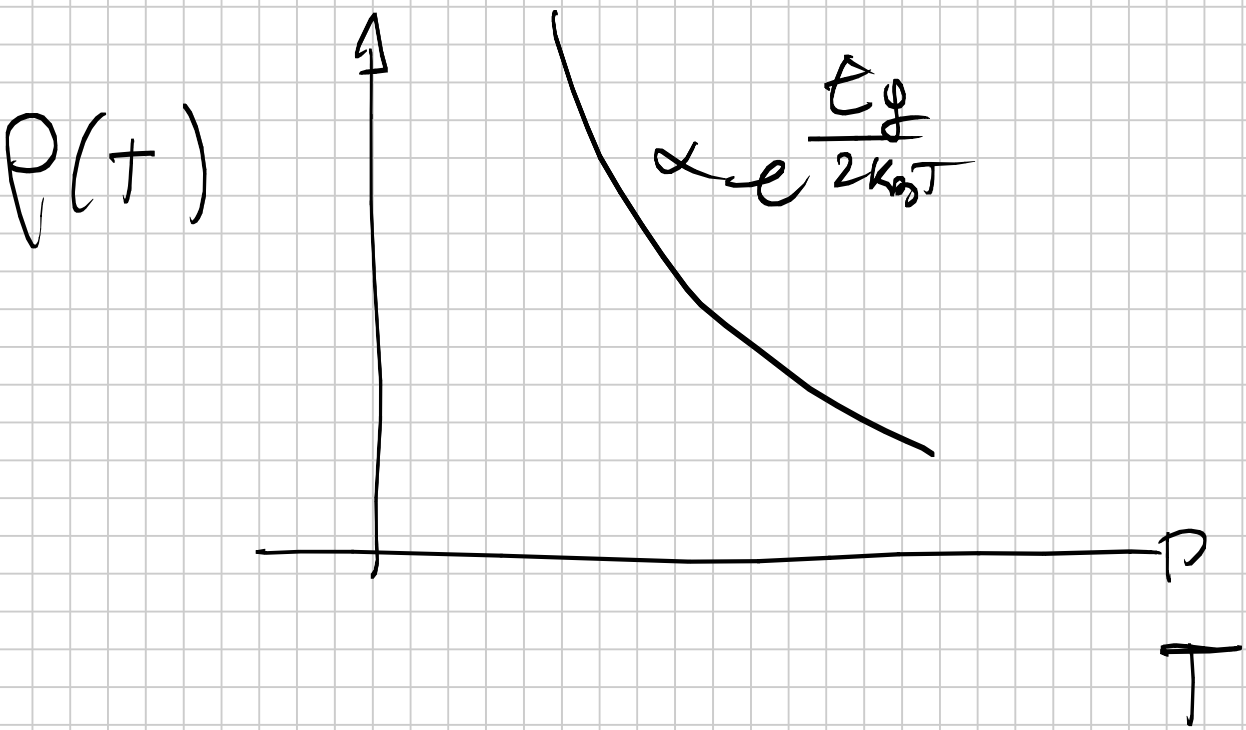
n → conduction e^- density

p → hole density

$$n \sim c' \, e^{-\frac{E_g}{2 k_B T}}$$

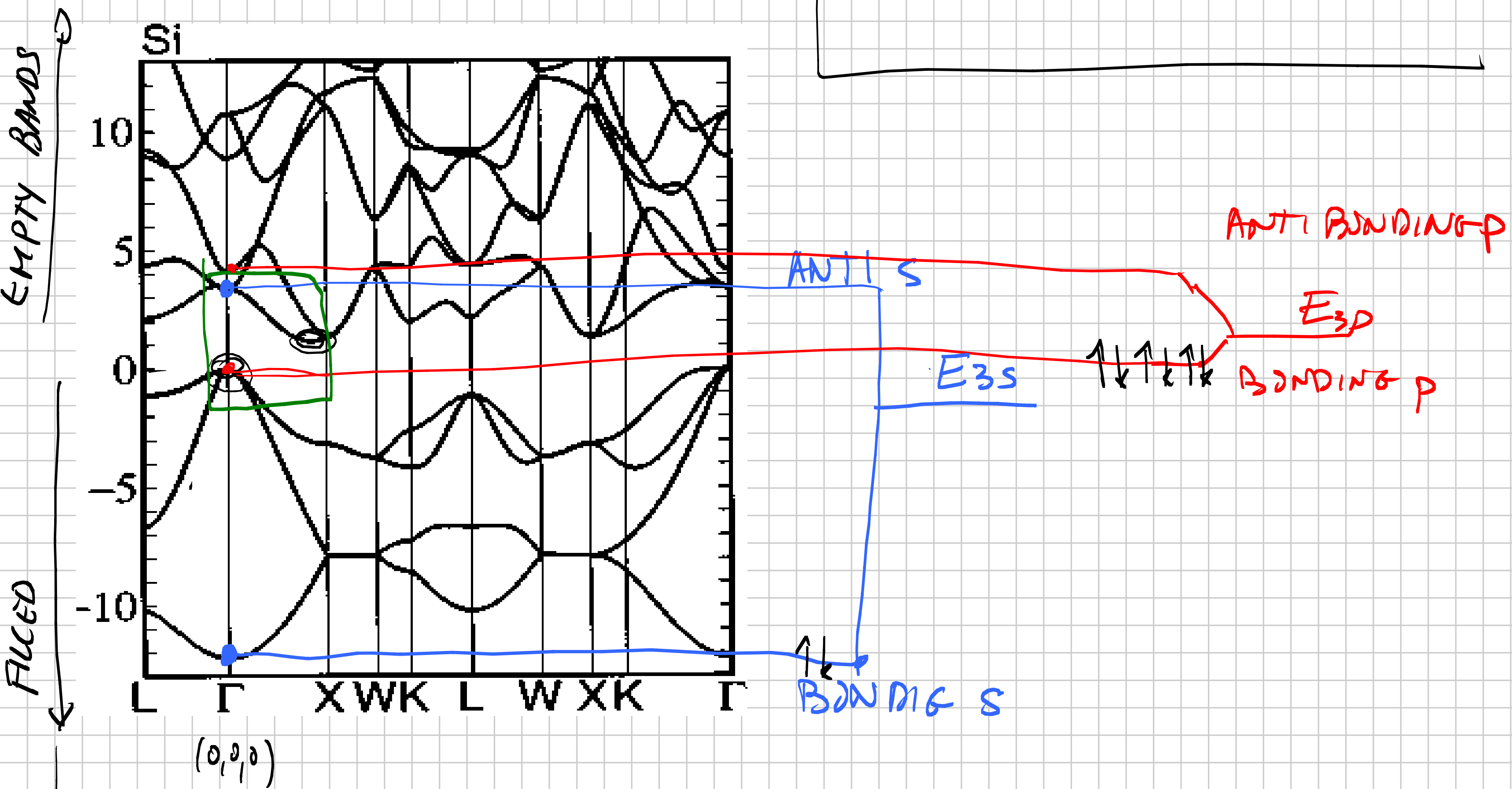
$$n = p$$

le l



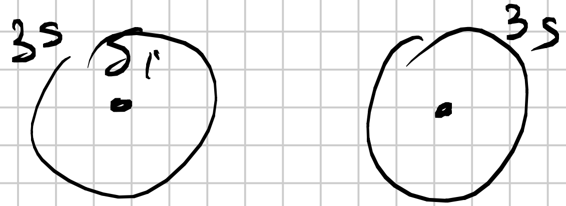
Si

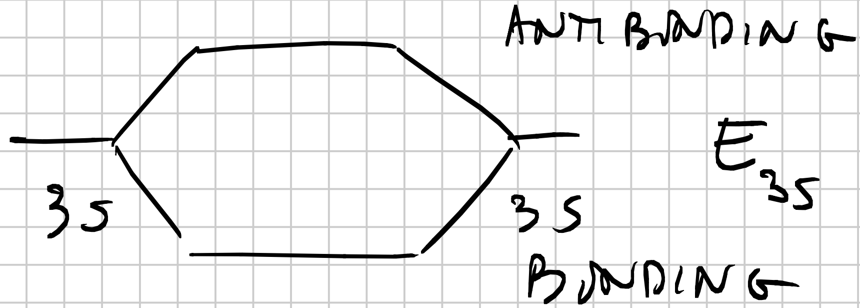
Si FCC with
2 Si atom per unit cell

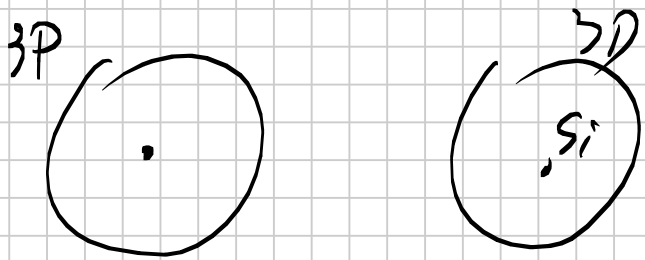


$Si = [Ne] (3s)^2 (3p)^2 \rightarrow 4 e^-$

2 Si in unit cell → 8 e^- per unit cell







$P_x \; P_y \; P_z$

EFFECTIVE MASS

$$E(k) = \frac{\hbar^2 k^2}{2m}$$

$$\frac{1}{m} = \frac{1}{\hbar^2} \frac{d^2 E(k)}{dk^2}$$

FREE PARTICLE

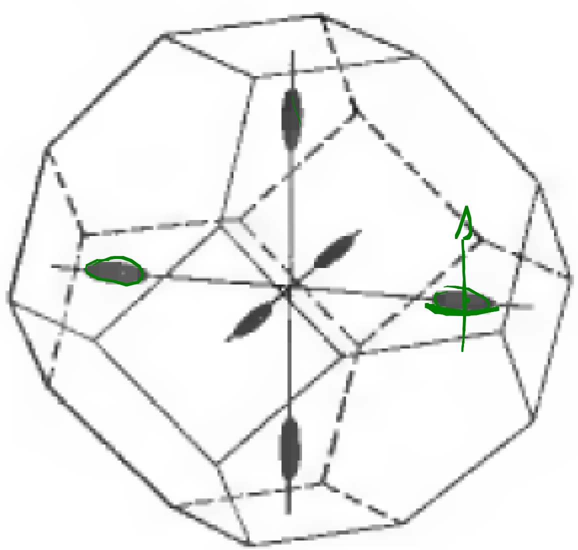
BLOCH ELECTRON $\mathcal{E}(k_x, k_y, k_z)$

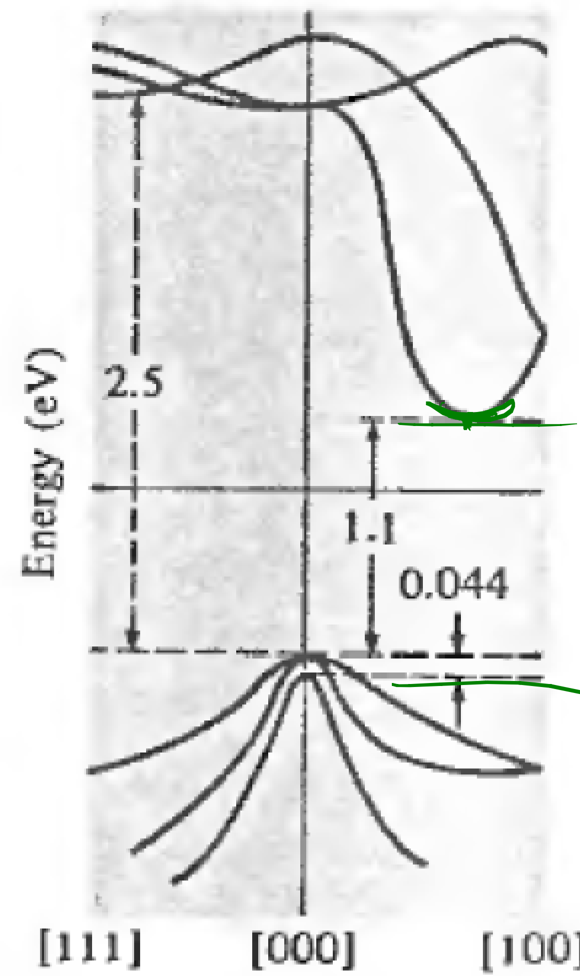
MASS TENSOR

$$\left(\frac{1}{m}\right)_{ij} = \frac{1}{\hbar^2} \frac{\partial^2 \mathcal{E}(k_x, k_y, k_z)}{\partial k_i \, \partial k_j}$$

$i, j \in \{x, y, z\}$

→ BZ





$m_{eL} \sim m_{xx} \sim 1\ m_e$ ← vacuum value

$m_{eT} \sim 0.2\ m_e$

VALLEY DEGENERACY FOR e IN SILICON

TOP VALENCE SPIN-ORBIT EFFECTS ARE IMPORTANT

P ELECTRONS

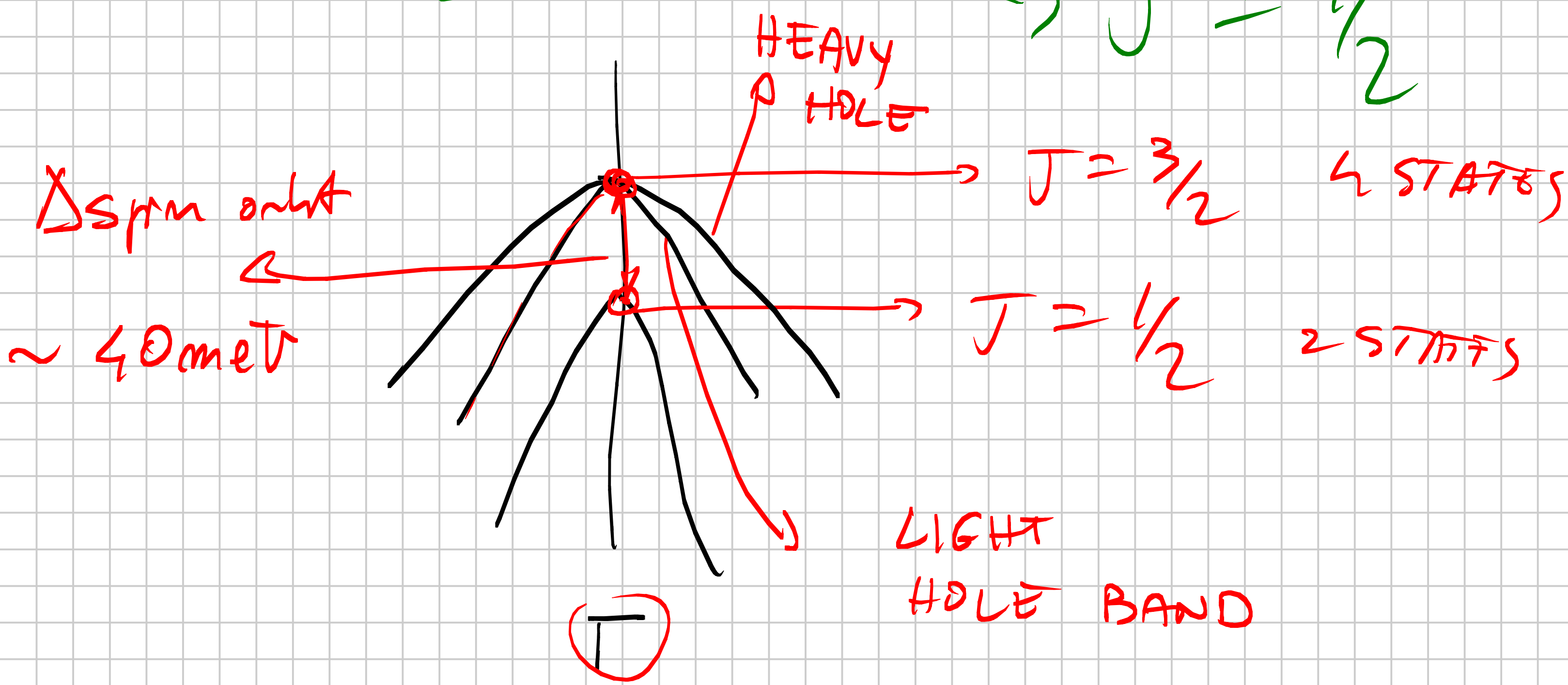
$H_{spin\text{-}orbit} \sim \alpha\, L \cdot S$

$L = 1$

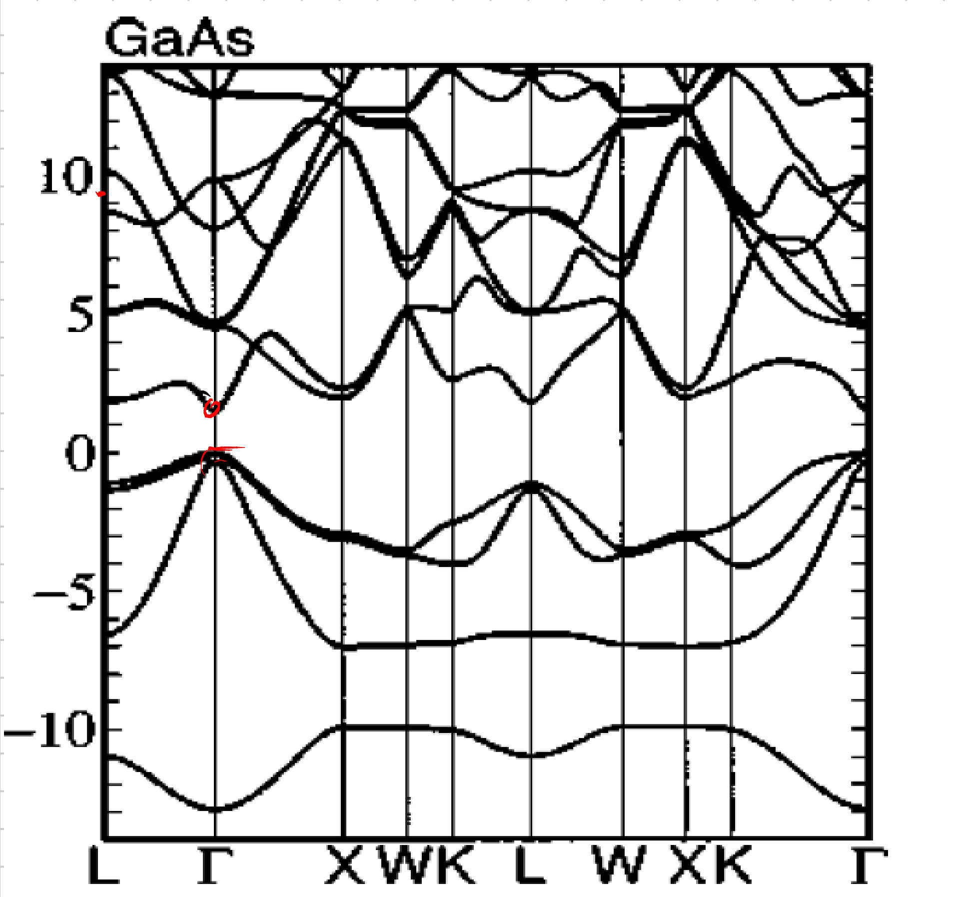
$S = 1/2$

→ $J = 3/2$ — 4 STATES

→ $J = 1/2$ — 2 STATES



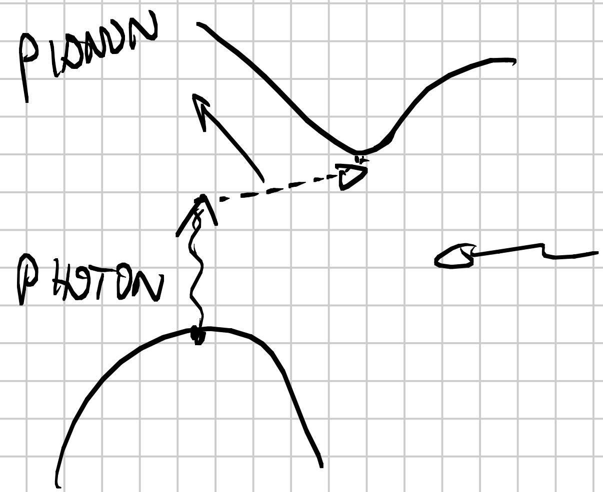
Ge GaAs $\Delta_{SO} \sim 300$ meV



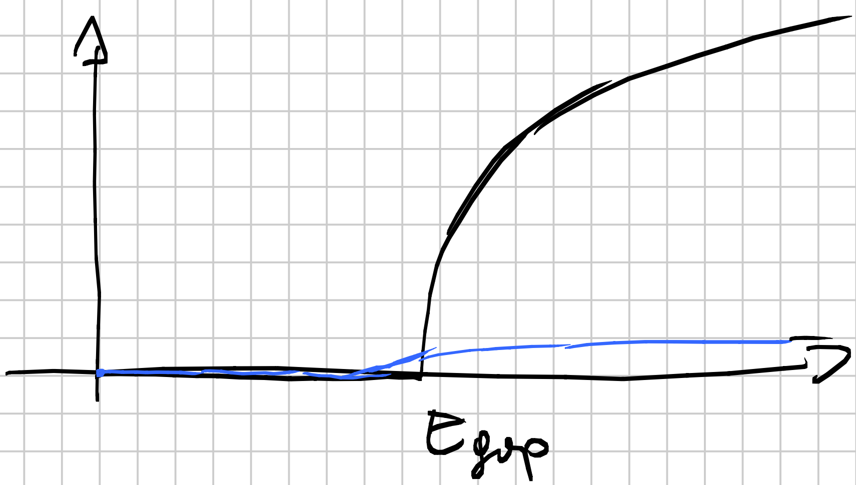
s like

p like

DIRECT GAP



$\alpha(E)$
↓
light absorption

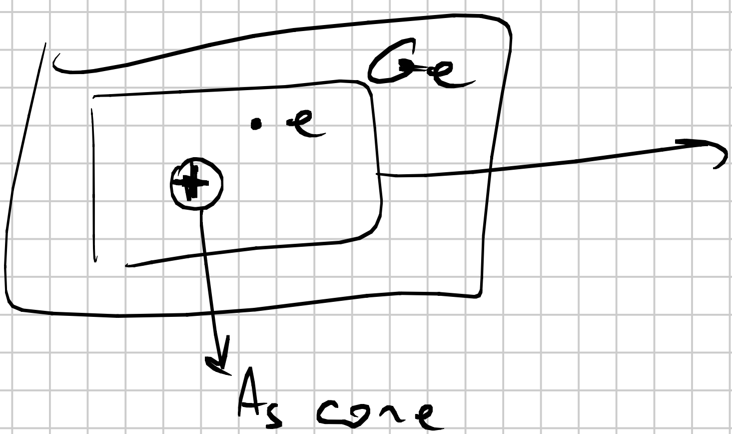


DOPING

Ge ~ $[Xe]\ 3d^{10} (4s)^2 (4p)^2$

↓ REPLACE ONE Ge WITH

As → $[Xe]\ 3d^{10} (4s)^2 (4p)^3$



Hydrogenic system

Coulomb $\dfrac{e^2}{\varepsilon r}$

ε dielectric constant

m effective mass

$E_b \sim 13\ \text{meV}$

AT $T = 0$ Valence band filled
and All Hydrogenic systems
bound

$E_b \sim 13$ meV $\ll E_{gap}$

AT finite T $n \sim e^{-\frac{E_{binding}}{k_B T}}$

As is a DONOR