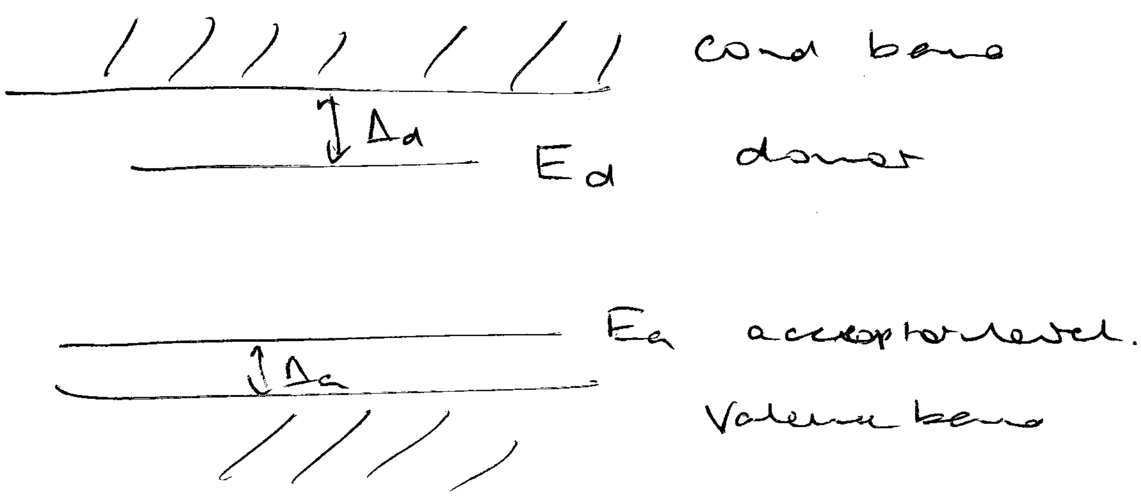
(3) Impurity doping of a semiconductor occurs by replacing a lattice ~~atom~~ atom by an impurity of a different charge.

eg: Si: As — group $\underline{V}$ element adds 5 electrons but also a charge $Z=5$. — in comparison to Si it looks like a charge of $+1$ with also an added electron.

Ionisation energy is like a H atom, but with $\Delta \sim \text{Rydberg} \dfrac{(m^*/m_e)}{\varepsilon^2}$.

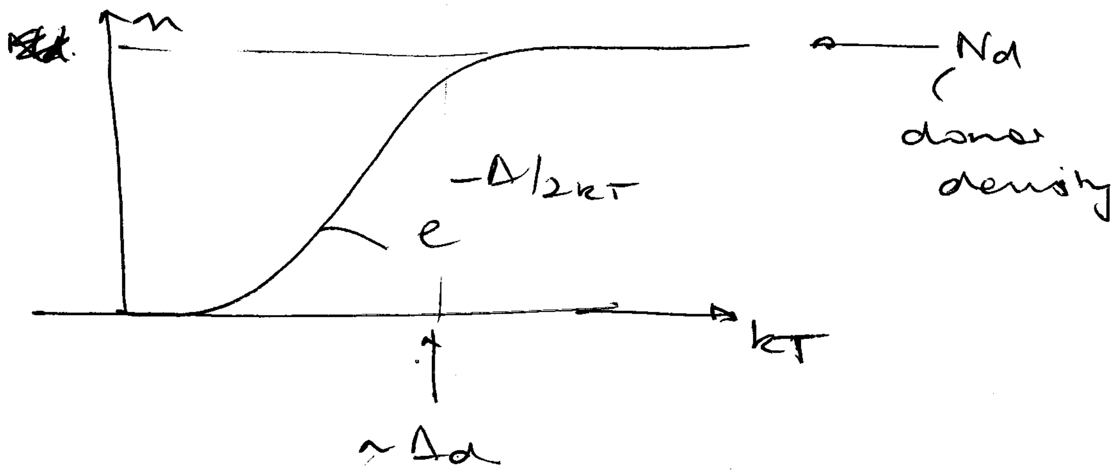
which may be small — $\lesssim kT$ at RT. Hence carriers are added. — here electrons from a donor impurity.

Alternatively, if the ionic charge is smaller — say Si: B then the impurity level adds holes. (donor)



The carrier density will generally be activated $\sim e^{\Delta/2kT}$ for $\Delta \gg kT$

but then saturate $\sim N_d, N_a$ density at large T.



(a) $$\Delta \sim \frac{13.6\,\text{eV}\,(0.066)}{13^2}$$

$$= 5.3 \text{ meV}.$$

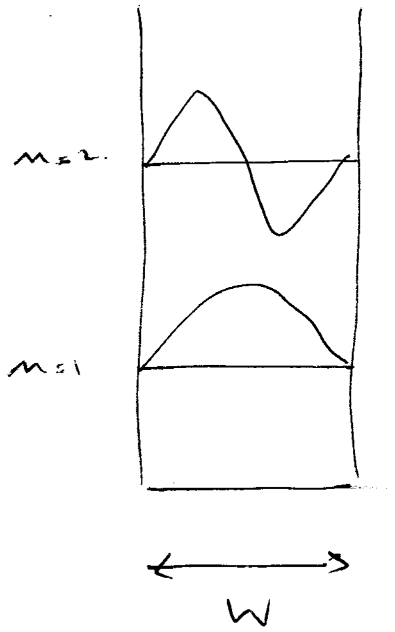
Bohr radius $a^* = \dfrac{a_0\, \varepsilon}{m^*/m} \simeq 10 \text{ nm}.$

— just about falls inside the well so use the 3D result.
(otherwise 2D Rydberg is 4 times as big!)

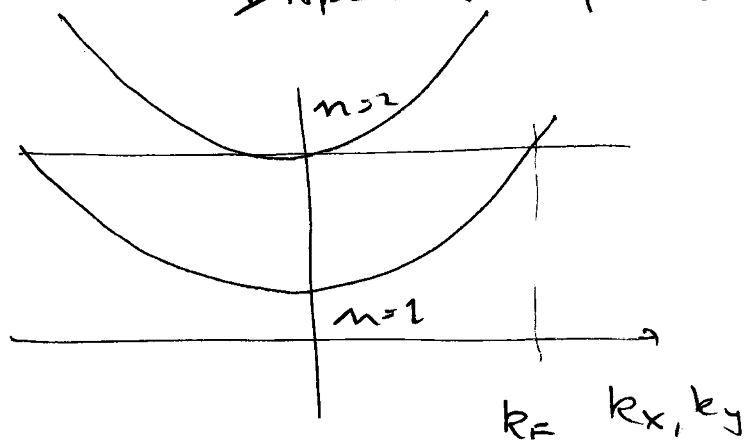
Metallisation if $N \sim \left(\dfrac{1}{a^*}\right)^3 \sim 10^{24}\,m^{-3}.$

$\sim 10^{16}\,m^{-2}.$

(b) Quantum well



Dispersion in plane



$$E_n = \frac{h^2}{8m^*} \cdot \frac{1}{W^2} \cdot n^2$$

$$E_F = \frac{\hbar^2 k_F^2}{2m^*} \quad \text{(if in lowest band)}$$

$$\frac{2\pi k_F^2}{(2\pi/L)^2} \cdot 2 = N \implies k_F^2 = \pi n$$

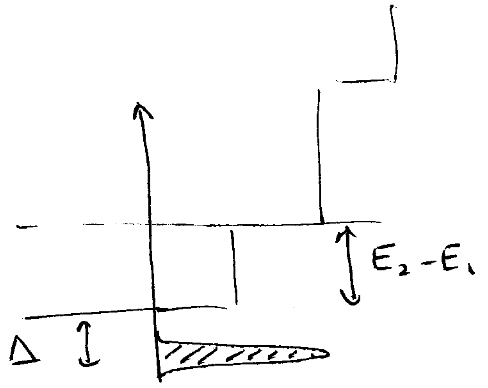
where n = 2D density.

$$\therefore \frac{\hbar^2}{2m^*} \cdot \pi n_{max} = E_2 - E_1$$

$$n_{max} = \frac{\cancel{2m^*}}{\cancel{\hbar^2}} \cdot \frac{1}{\pi} \cdot \frac{h^2 \, (4\pi)^2}{\cancel{8m^*}} \cdot \frac{1}{W^2} \cdot 3$$

$$= \frac{3\pi}{W^2} \sim \frac{10}{10^{-16}} \simeq 10^{17} \, m^{-2}$$

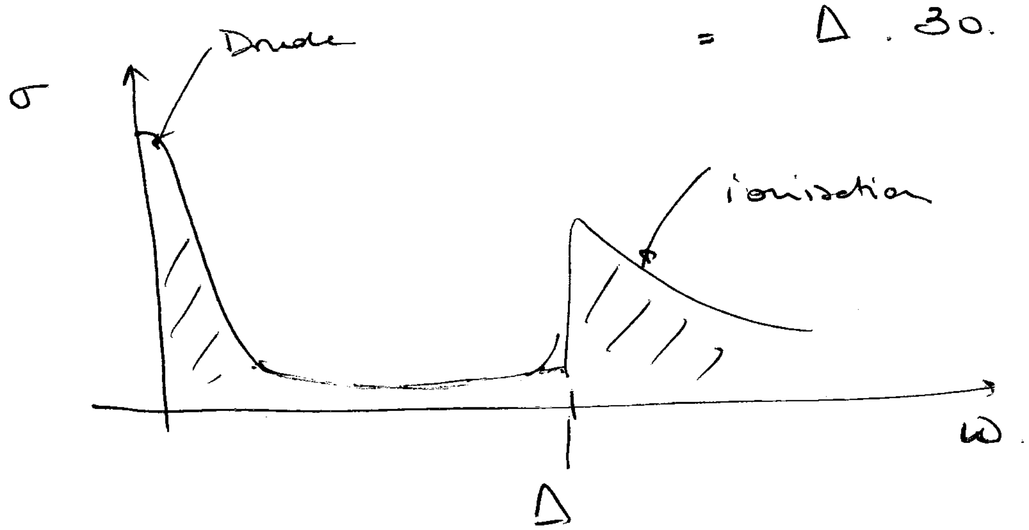
Case (a)



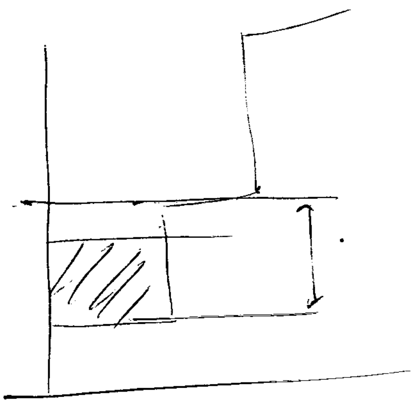
Density of states

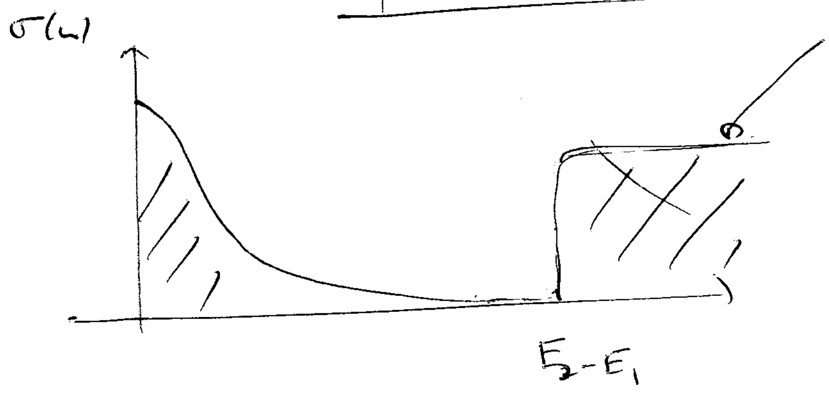
$$\Delta \sim 5\,\text{meV}, \quad E_2 - E_1 = \frac{\hbar^2}{2m^* a_0^2} \cdot \left(\frac{\pi^2 a_0^{*2}}{W^2}\right) \cdot 3$$

$$= \Delta \cdot 30.$$



Case (b)





This will exist depending on polarization $\perp^r$ plane

— dipole allowed since

$n=2$ state odd

$n=1$ state even