intrinsic : $n \simeq p$ since all promoted electrons leave holes behind

$n^2 = \ldots$

$$n = 2\left(\frac{kT}{2\pi\hbar^2}\right)^{3/2} (m_e m_h)^{3/4} e^{-E_g/2kT}$$ "n_i" i = intrinsic

Also have when $n = p$,

$$\cancel{2}\left(\frac{m_e kT}{\cancel{2\pi\hbar^2}}\right)^{3/2} e^{-(E_c-\mu)/kT} = \cancel{2}\left(\frac{m_h kT}{\cancel{2\pi\hbar^2}}\right)^{3/2} e^{-(\mu-E_v)/kT}$$

$$e^{2\mu/kT} = \left(\frac{m_h}{m_e}\right)^{3/2} e^{(+E_c-E_v)/kT}$$ ← Track down negative sign!

$$\mu = \frac{kT}{2} \ln\left[\;\circlearrowleft\;\right]$$

$$= \frac{kT}{2}\left[\frac{3}{2}\ln\left(\frac{m_h}{m_e}\right) + \frac{E_g}{kT}\right]$$

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

Side Note: next page is [illegible] discusses "mobility" which is $\frac{\text{conductivity}}{n \cdot e}$

"If you have charges, how easily do they move?"

also $\frac{v}{E}$

hazards: mobility also given symbol μ

μ_e = electron mobility

μ_h = hole mobility

Subscripts are critical warning that the symbol μ now has completely unrelated meaning!

Recall $\sigma = \frac{ne^2\tau}{m}$ → $\mu_e = \frac{ne^2\tau/m}{ne} = \frac{e\tau}{m}$

↑ Conductivity dominated by temperature dependence of n. (τ more weakly dependent on temp.)

Doping

Ex.

← 4 electrons to covalent bonds
+ 1 extra electron (and extra proton)

"Donor"

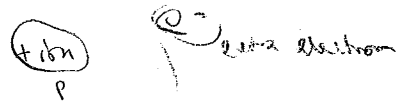
"n-type"

Differences

1) extra electron moves around Silicon w/ effective mass m^*

2) positive charge screened by core electrons
→ dielectric constant, as usual with materials.
ϵ_r
↳ this is called relative dielectric const. ϵ.

Table of ϵ on pg 211 Table 4



Attraction just like (+) (−) hydrogen

hydrogen → Donor

ionization (binding) energy

$$E = \frac{e^4 m}{2(4\pi\epsilon_0)^2\hbar^2} \longrightarrow$$

$$= 13.6\text{ eV} \qquad = \boxed{\frac{13.6\text{ eV}}{\epsilon_r^2}\left(\frac{m^*}{m}\right)}$$

Bohr radius $a_0 = \dfrac{4\pi\epsilon_0\hbar^2}{me^2}$ $= \boxed{.53\text{ Å}\ \dfrac{\epsilon_r}{m^*/m}}$

$= .53\text{ Å}$

P donor in Si: $m^* = .2m$, $\epsilon = 11.7$

$\boxed{E_d = 20\text{ meV}}$ ← ground state = 20 meV below CB min

10-60 meV

↓

$\boxed{a_0 = 30\text{ Å}}$

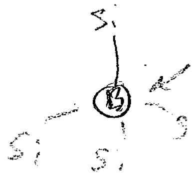
30-80 Å

= 24 I meV

using diff m^* values,
predicted E_d = 20 meV
measured = 39.42 meV

"Acceptor"

([illegible])



← 4 electrons to covalent band + 1 extra hole (and neg. charged nucleus)

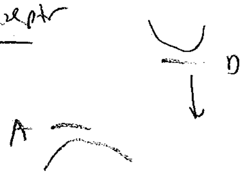
hole binding to neg. nucleus → same ionization energy + Bohr radius

(except hole m^*, not electron m^*)

acceptor binding E

day 37 p1

Donor + Acceptor



electrons drop down to A level!

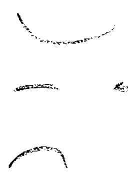
if $N_D > N_A$ n-type

$N_A < N_D$ p-type

"compensated" → roughly equal. or at GaAs, lots of both types

Amphoteric - ex. Si in GaAs, could be either

Nonhydrogenic



← states deep in band

tend to happen when big lattice distortion

because dopant not very like host

Background · unintentional $\approx 10^{14}$ cm^{-3} ($\approx$ 1 part in 10^9)

for best samples

intentional: often $\approx 10^{17} - 10^{18}$ cm^{-3}

(my own samples $3\cdot10^{14} - 3\cdot10^{16}$ cm^{-3})