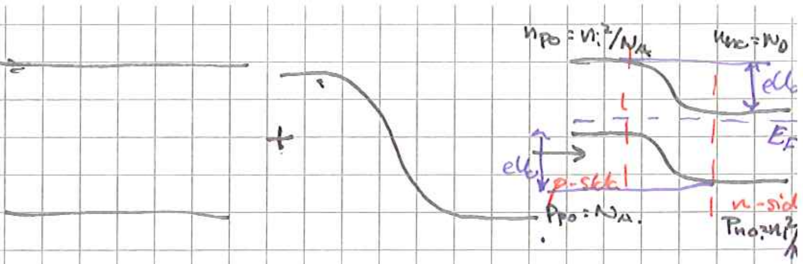
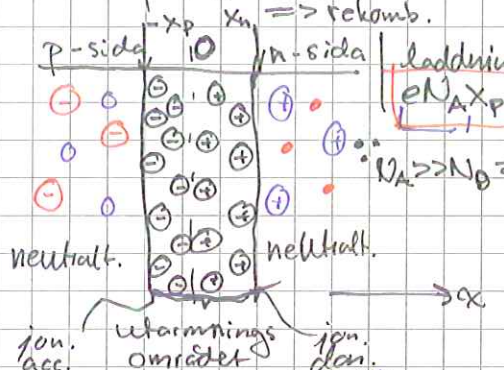
18/2-2013 (Se figur 7.1 s 161.)

(12) **pn-övergången**

$n = N_c e^{-(E_c - E_F)/kT} = N_D$ | "P lochar bort väggen" (fig 7.2 s 162)

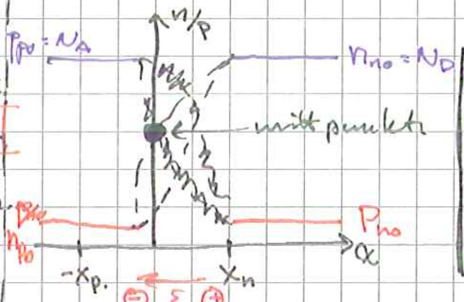
n-sidan: $p \cdot n_{n0} > n_i^2$ => rekomb.





laddningsneutralitet: $eN_A x_p = eN_D x_n$

$N_A >> N_D \Rightarrow x_p << x_n$



E_F konst: inga nettoflöden, inga strömmar.

kap 2: diffusionsbidrag

$F_e = -D_e \frac{dn}{dx}$

$F_h = +D_h \frac{dp}{dx}$

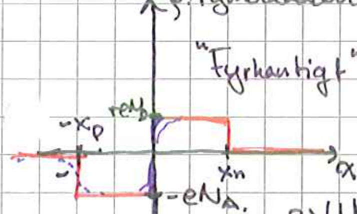
Drift: $J_{e/h} \propto \mathcal{E}$.

	diff	drift.	Σ
e^--flöde	←	→	0
hål-flöde	→	←	0.

(*) svart: framspänning (se nedan).

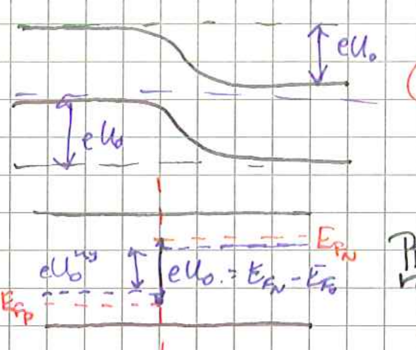
ρ: rymdladdning (C/m³).

"Fyrkantigt": En approximation



Antaganden:
1) Abrupt övergång
2) Utarmningsapproximationen (se s. 164)

Fråga:
En pn-övergång är dopad med $N_D = N_A$ och vi har full jonisering. Vad hade U_0 varit om båda dop-koncentrationerna hade varit hälften så stora.



A: hälften så stor
(B): mindre, men bara lite
C: större, men bara lite
D: Dubbelt så stor.

$p_{p0} = N_A = N_v e^{-(E_{F_p} - E_v)/kT}$ (lite större)

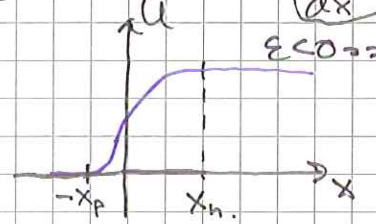
$n_{n0} = N_D = N_c e^{-(E_c - E_{F_N})/kT}$

$x_p \cdot N_A = x_n \cdot N_D$

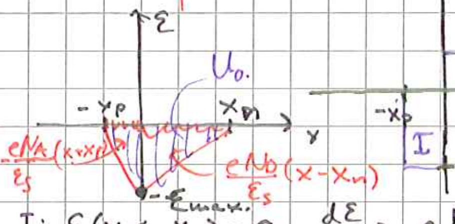
$\nabla \cdot \vec{\mathcal{E}} = \frac{\rho}{\varepsilon_s}$ ($\varepsilon_0 \cdot \varepsilon_r$) → 1 dim. $\frac{d\mathcal{E}}{dx} = \frac{\rho}{\varepsilon_s}$ ~ ①

elektrisk potential $\frac{dU}{dx} = -\mathcal{E}$ (3D: $\nabla U = -\vec{\mathcal{E}}$) ②

$\mathcal{E} < 0 \Rightarrow \frac{dU}{dx} > 0$.

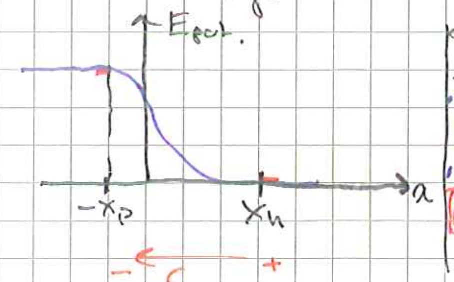


① o ②: $\frac{d^2U}{dx^2} = -\frac{\rho}{\varepsilon_s}$ Poissonekv.



I: $\mathcal{E}(x < -x_p) = 0$. $\frac{d\mathcal{E}}{dx} = -e\frac{N_A}{\varepsilon_s} = \frac{\rho}{\varepsilon_s}$

Potentiell energi hos e^-: $\Delta E_{pot} = (-e)U$, $\mathcal{E}(x) = \int_{-x_p}^{x} -\frac{eN_A}{\varepsilon_s} dx = -\frac{eN_A}{\varepsilon_s}(x_p + x)$



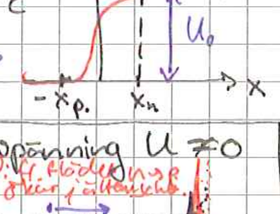
Termisk jämvikt:
- ingen pålagd spänning.
- inget ljus.

E_F konstant

II: Tänka!

$-\mathcal{E}_{max} = -\frac{eN_A}{\varepsilon_s} x_p = -\frac{eN_D}{\varepsilon_s} x_n$ (laddningsneutralitet).

$\int_{-x_p}^{x_n} \frac{dU}{dx} = \int_{-x_p}^{x_n} -\mathcal{E}$



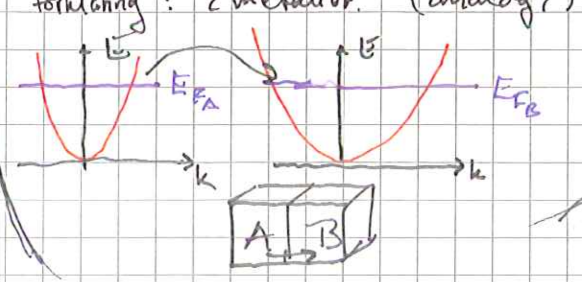
$\int_{-x_p}^{x_n} \frac{dU}{dx'} dx' = -\int_{-x_p}^{x_n} \mathcal{E}(x') dx'$ = $\mathcal{E}_{max} \cdot W = U_0$

$= \frac{e N_D N_A}{2\varepsilon_s (N_D + N_A)} W^2$

$W = x_n + x_p = \frac{\mathcal{E}_{max} \cdot \varepsilon_s}{e} \cdot \left(\frac{1}{N_D} + \frac{1}{N_A}\right)$

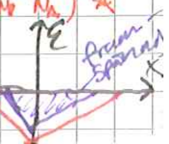
$\Rightarrow W = \sqrt{\frac{2\varepsilon_s U_0 (N_D + N_A)}{e N_D N_A}}$

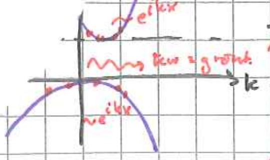
"förklaring": 2 metaller. (analogi).

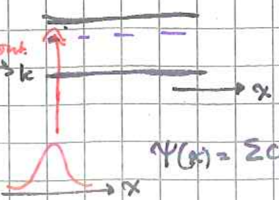


(*) Yttre spänning $U \neq 0$

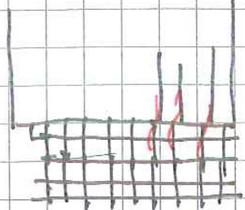
Se fig 7.12 s 170.

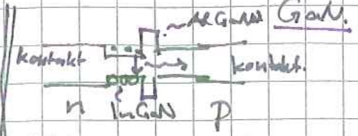






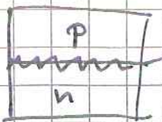
$\Psi(x) = \sum_k c_k e^{ikx}$





ITO - Indium Tenoxide

Både ledande och transparent.



piezo elektriska fält.

Kap 7. pn-övergång

E_c — n_{p0}

min. laddnings bärare

$p_{n0} = N_D$: Maj. laddnings bärare

E_{F_n}

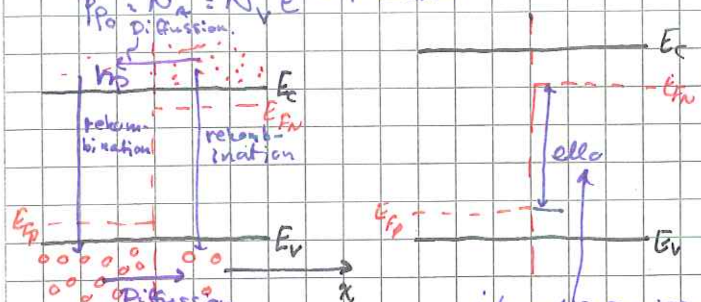
E_{F_p}

E_v

$p_{p0} = N_A$ p-sidan

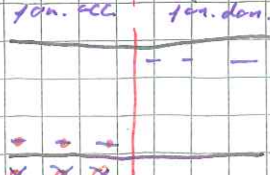
$p_{n0} \approx \frac{n_i^2}{n_{n0}} = \frac{n_i^2}{N_D}$ n-sidan

$p_{p0} = N_A = N_v e^{-(E_{F_p}-E_v)/kT}$



tänkt vägg som vi tar bort!

inbyggd spänning
diffussionsspänning.

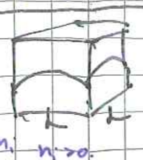


Sem-pass:

6. 3D-kvantbrunn

$\phi(x,y,z) = A \sin(k_x x) \cdot \sin(k_y y) \cdot \sin(k_z z)$

$k_i = \frac{\pi}{L} \cdot n_i$, $n > 0$.

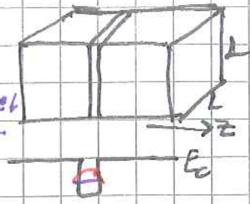


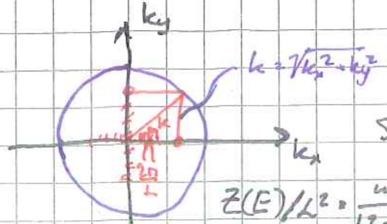
2D:

12. 2D-elektrongas

$\Psi \sim e^{ik_x x} \cdot e^{ik_y y} \cdot \phi(z)$ — $\frac{2\pi}{L} \cdot n$, $n = 0, \pm 1, \pm 2 \ldots$

$E = \frac{\hbar^2}{2m}(k_x^2 + k_y^2)(+E_z)$

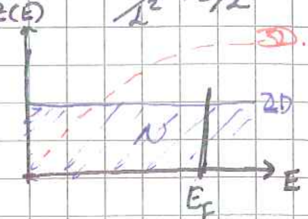




$S(k) = \frac{\pi k^2}{\left(\frac{2\pi}{L}\right)^2} \cdot 2.$ $E = \frac{\hbar^2 k^2}{2m}$

$S(E) = \ldots$ $Z(E) = \frac{dS}{dE} / L^2$

$Z(E)/L^2 = \frac{m}{\hbar^2 \pi}$



Fermi energin: E_F

i) $N = n \cdot L^2 = \int_0^{E_F} Z(E) \cdot dE$ eller

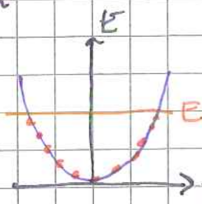
$n = \int_0^{E_F} Z(E)\, dE$ — Z per ytenhet.

$E_F = \frac{n \pi \hbar^2}{m}$

ii) $S(E) = \frac{2mE}{2\pi\hbar^2} L^2$. Om $E = E_F$, då är $S(E) = N$.

$\frac{2mE_F}{2\pi\hbar^2} L^2 = N = n L^2$

16.

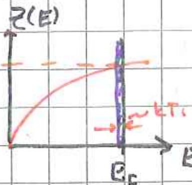


$C_V = \frac{dE}{dT}$ $E(T) = E(0) + \int_0^{\infty} E Z(E) F(E) dE$ — T

I kompendiet: (appr. 1) egentligen...

$E(T) = E(0) + kT \cdot Z(E_F) \cdot kT = \frac{3}{2} kT \cdot \frac{N}{E_F} \cdot k$

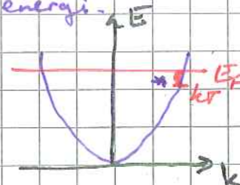
Antal e^- som kan ändra energi.



I uppgiften (appr 2).

$\frac{kT}{E_F} \cdot N \cdot kT$

antal som kan ändra energi.



17). atomära vibrationer

$E(T) = N_{atom} \cdot 3kT$ — $3 \cdot \frac{kT}{2}$ — $\frac{p_x^2}{2m} + \frac{M}{2}\omega^2 x^2$

el. Klassiska: $E = N_{el} \cdot \frac{3}{2} kT$, $C_V = \frac{3}{2} N_{el} \cdot k$

FEM: $E = \frac{3}{2} N \frac{k^2 T^2}{E_F}$, $C_V = 3N \frac{kT}{E_F} \cdot k$

$p = \hbar k = m v$