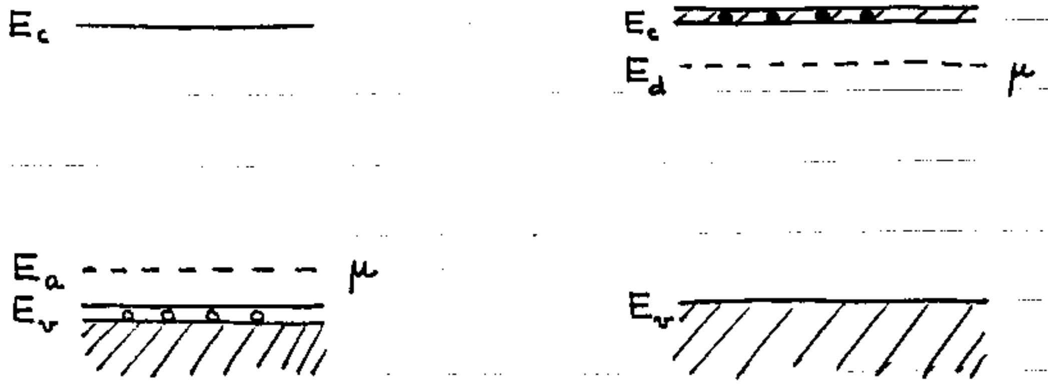
pn - overgang

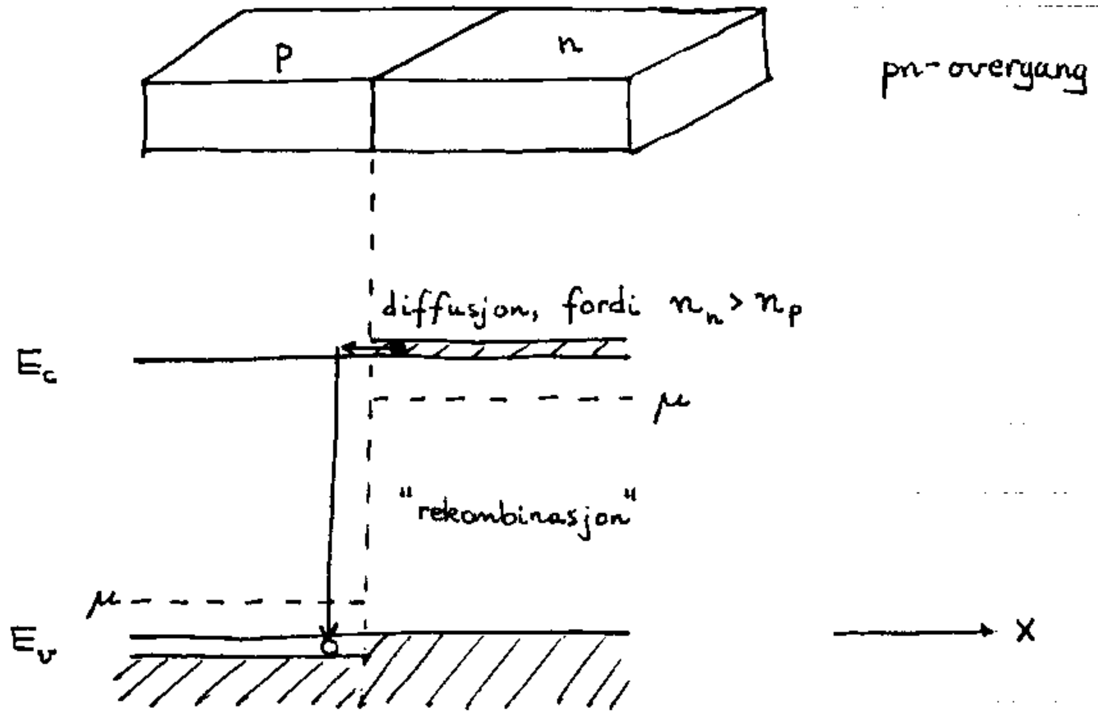
fylte tilstander
• elektron
o hull

p-type: n-type:



p-type: $p \gg n$, $p \approx N_{A^-}$

n-type: $n \gg p$, $n \approx N_{D^+}$



<u>Ikke likevekt</u>! Systemet får lavere energi ved å flytte elektroner fra n-siden (energi $E \approx E_c$) til p-siden ($E \approx E_v$)

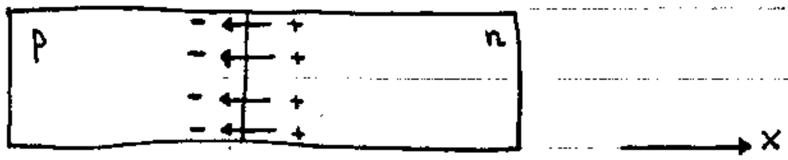
Diffusjonsstrøm : $j_n\,(\text{diff.}) = e\,D_n \frac{dn}{dx}$ (elektroner)

$j_p\,(\text{diff.}) = -e\,D_p \frac{dp}{dx}$ (hull)

⇒ overskudd av ⊖ på p-siden

— " — ⊕ på n-siden

⇒ elektrisk felt $\vec{E}$ ved overgangen:



$$\vec{E} = -\frac{dV}{dx}\hat{x}$$

Strøm pga elektrisk felt: $j_n(\text{drift}) = -n e v_n$

$$= -n e \mu_n \frac{dV}{dx} \quad \text{(elektroner)}$$

$$j_p(\text{drift}) = -p e \mu_p \frac{dV}{dx} \quad \text{(hull)}$$

D_n, D_p : diffusjonskoeffisienter

μ_n, μ_p : mobiliteter

<u>Likevekt</u> når $j(\text{total}) = j(\text{diff}) + j(\text{drift}) = 0$

$$\Rightarrow \quad e D_n \frac{dn}{dx} - n e \mu_n \frac{dV}{dx} = 0 \quad \text{(elektroner)}$$

$$e D_p \frac{dp}{dx} + p e \mu_p \frac{dV}{dx} = 0 \quad \text{(hull)}$$

Innebygd potensial:

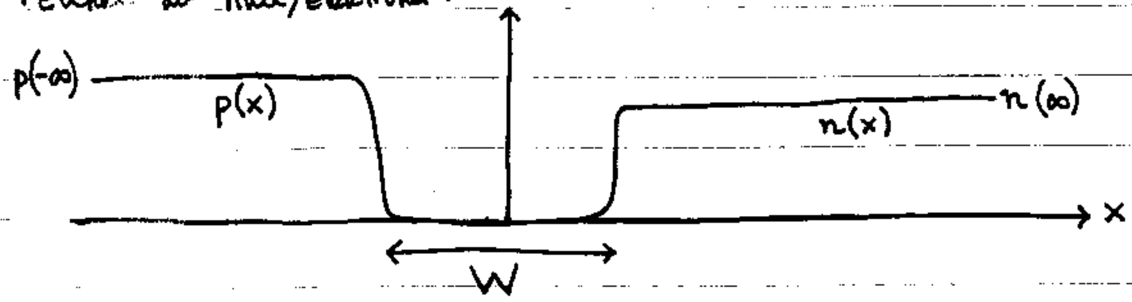
$$\Delta V = V(\text{n-siden}) - V(\text{p-siden}) = -\int_{-\infty}^{\infty} E_x \, dx$$

Netto-ladning ≠ 0 i område med utstrekning W i x-retning : <u>sperresonen</u> ("depletion layer")

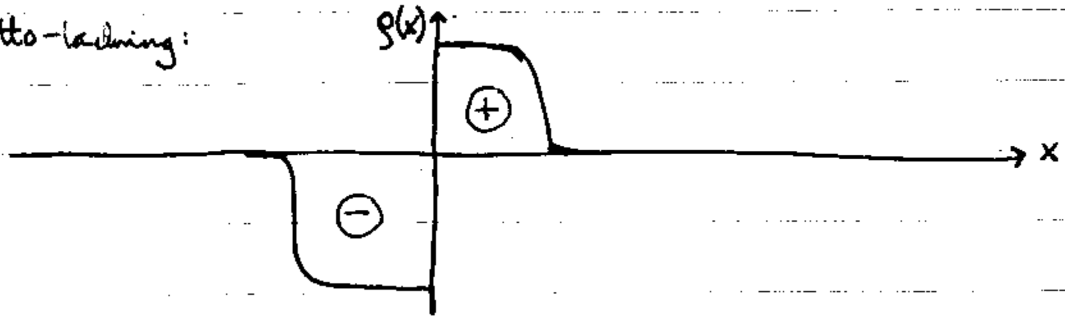
W ~ 100 – 10000 Å

Her fra 26.03.03

Tetthet av hull/elektroner:

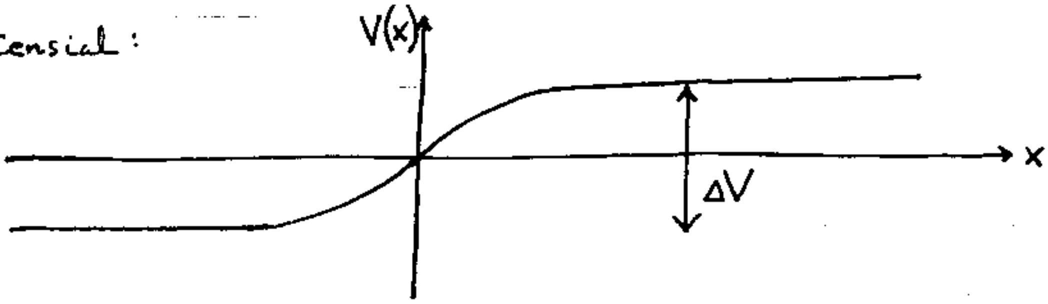


Netto-ladning:

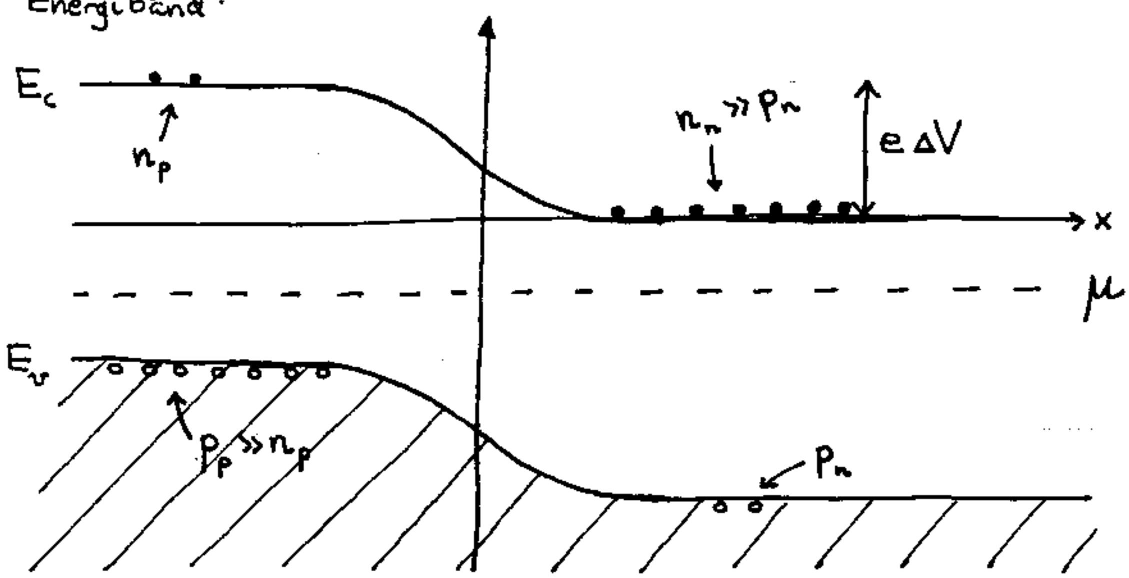


Hit 19.03.03.

Potensial:



Energibånd:



Likevekt: Konstant kjemisk potensial μ

Eks: Si ved $T = 300\,K$, $n_i = p_i \approx 10^{10}\ cm^{-3}$

$\Rightarrow n \cdot p = n_i^2 = 10^{20}\ cm^{-6}$ (massevirkningsloven)

Doping: $N_D = 10^{16}\ cm^{-3}$ (n-siden; feks. As)

$N_A = 10^{16}\ cm^{-3}$ (p-siden; feks. B)

$\Rightarrow n(\infty) \approx N_D = 10^{16}$
$p(-\infty) \approx N_A = 10^{16}$
} antar fullstendig ionisering

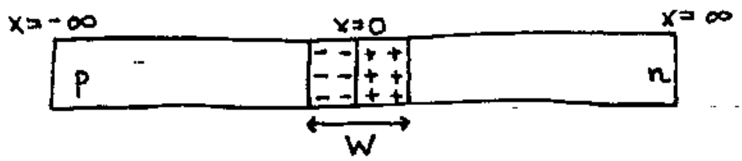
$\Rightarrow p(\infty) \approx 10^4$, $n(-\infty) \approx 10^4$

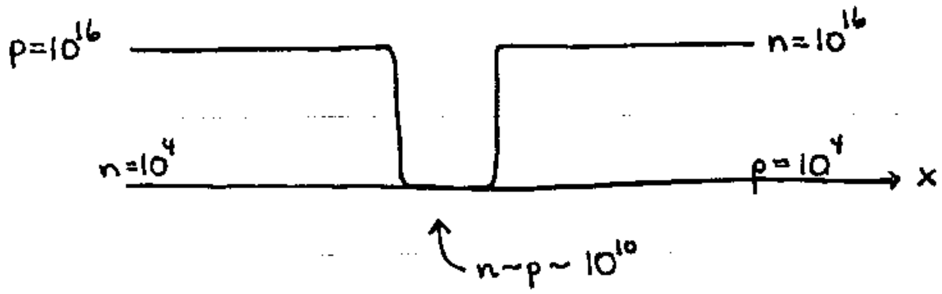
I sperresonen: $n, p \sim n_i \sim 10^{10} \ll N_D, N_A$

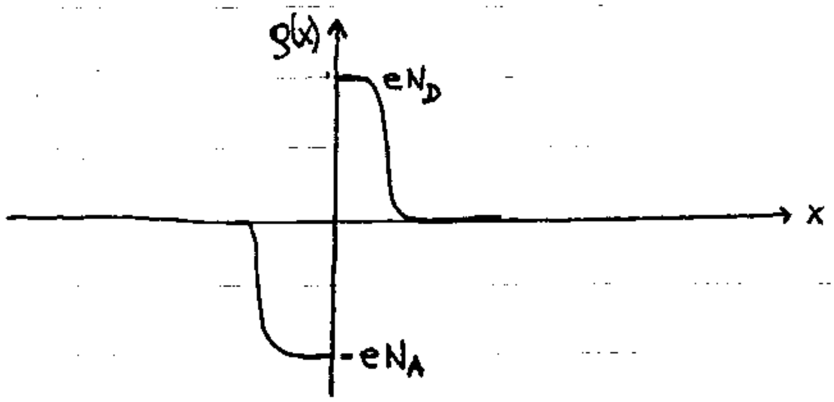
$\Rightarrow \rho(x<0) \approx -eN_A$

$\rho(x>0) \approx eN_D$

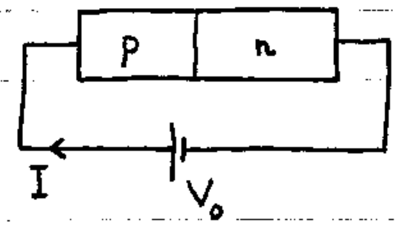
(I sperresonen er $n \approx p \approx 0$ pga diffusjon og påfølgende rekombinasjon.)



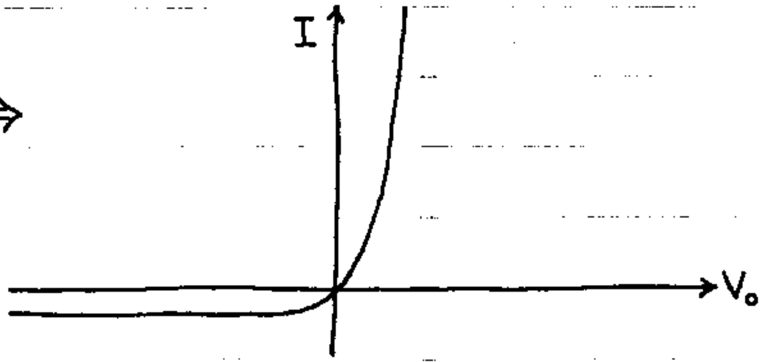




Med ytre påtrykt spenning:

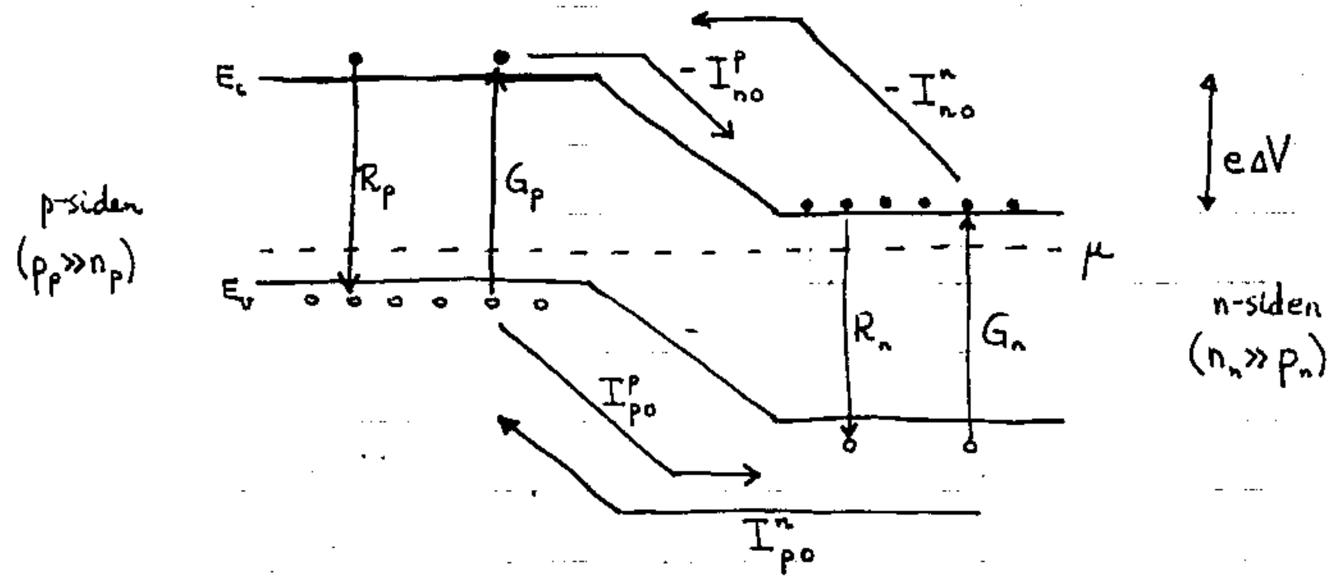


⇒



(Hvorfor?)

Dynamisk likevekt nær sperresonen:



I likevekt:

$G_n = R_n$, $G_p = R_p$ (genereringsrate = rekombinasjonsrate)

$$I^n_{no} + I^p_{no} = 0$$

$$I^p_{po} + I^n_{po} = 0$$

"Kommentar": $I_n^p = I_{no}^p = -I_{no}^n$

$I_p^n = I_{po}^n = -I_{po}^p$

$$\Rightarrow I_n^{total} = I_n^n + I_n^p = I_{no}^{n} \left(e^{\frac{eV_0}{k_B T}} - 1\right)$$

$$I_p^{total} = I_p^p + I_p^n = I_{po}^p \left(\text{—}\,''\,\text{—} \right)$$

$$\Rightarrow I^{total} = I_n^{total} + I_p^{total} = I_0 \left(e^{\frac{eV_0}{k_B T}} - 1\right)$$

$$\left(I_0 = I_{no}^n + I_{po}^p \right)$$

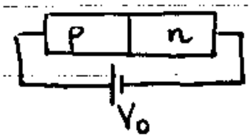
$I^p_{n0} \sim n_p$ (liten pga liten n_p)

$I^n_{p0} \sim p_n$ (—— " —— p_n)

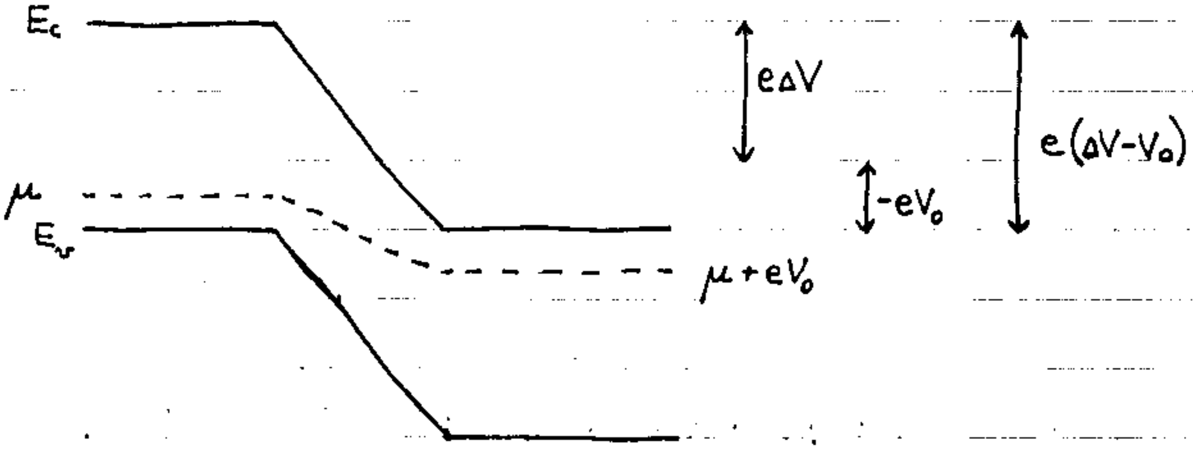
$I^n_{n0} \sim n_n\, e^{-\frac{e\Delta V}{k_B T}}$ (—— " —— $e^{-\frac{e\Delta V}{k_B T}}$)

$I^p_{p0} \sim p_p\, e^{-\frac{e\Delta V}{k_B T}}$ (—— " ——)

Med ytre spenningskilde V_0 :
(ikke lenger likevekt!)



$V_0 < 0 \;\Rightarrow\; -e\Delta V \rightarrow -e(\Delta V - V_0)$



$I^p_n \approx I^p_{n0}$
$I^n_p \approx I^n_{p0}$
} omtrent uendret; fremdeles få elektroner (hull) på p-siden (n-siden)

$I^n_n = I^n_{n0}\, e^{eV_0/k_B T}$
$I^p_p = I^p_{p0}\, e^{eV_0/k_B T}$
} "barrieren" <u>økt</u> fra $e\Delta V$ til $e(\Delta V - V_0)$; strømbidragene <u>redusert</u> med faktor $\exp\left(\frac{eV_0}{k_B T}\right)$

Alt i alt: $I(V_0) = I_0 \left(e^{eV_0/k_B T} - 1\right)$ (se side 51 B)

$(\Rightarrow I(0) = 0,$ OK $)$

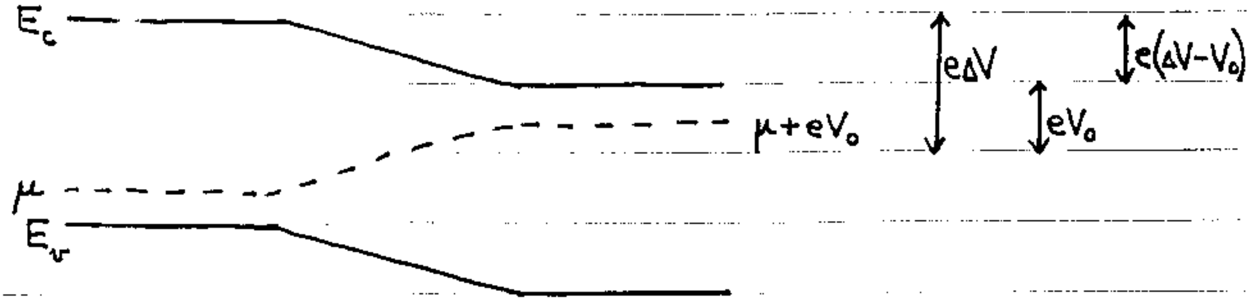
For <u>små</u> V_0, dvs $e|V_0| < k_B T$: $e^{\frac{eV_0}{k_B T}} \approx 1 + \frac{eV_0}{k_B T}$

$$\Rightarrow I(V_0) \approx \frac{I_0 e}{k_B T} V_0$$

): som motstand med $R = \frac{k_B T}{I_0 e}$

(der I_0 også er temperaturavhengig)

$V_0 > 0 \Rightarrow -e\Delta V \rightarrow -e(\Delta V - V_0)$



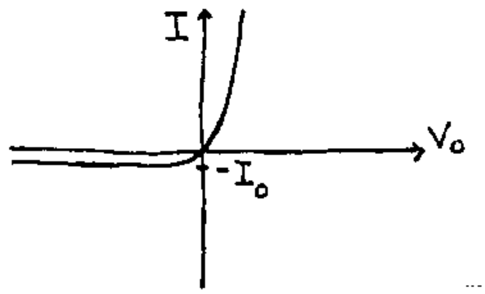
$$\left.\begin{aligned} I_n^p &\approx I_{n0}^p \\ I_p^n &\approx I_{p0}^n \end{aligned}\right\} \text{ omtrent uendret}$$

$$\left.\begin{aligned} I_n^n &= I_{n0}^n \, e^{eV_0/k_BT} \\ I_p^p &= I_{p0}^p \, e^{eV_0/k_BT} \end{aligned}\right\}$$

barrieren redusert til $e(\Delta V - V_0)$; strømbidragene økt med faktor $\exp\left(\frac{eV_0}{k_BT}\right)$

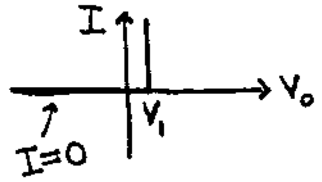
Nok en gang: $$\boxed{I(V_0) = I_0 \left(e^{eV_0/k_BT} - 1 \right)}$$

Strøm-spennings-karakteristikk for ideell diode

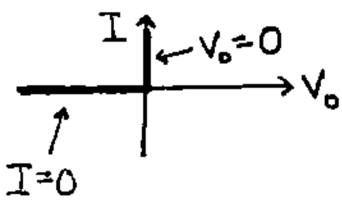


Ideell diode

Idealisering 1:



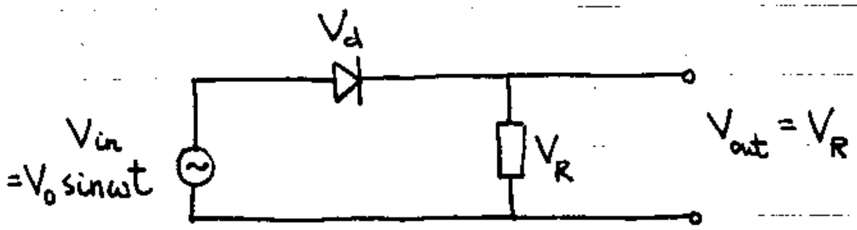
Idealisering 2:



Kretssymbol for diode:

$$V_0 < 0 \Rightarrow I = 0$$
$$I > 0 \Rightarrow V_0 = 0$$

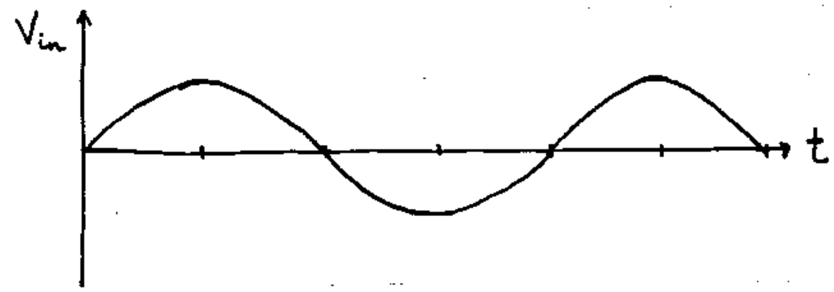
Likeretter:

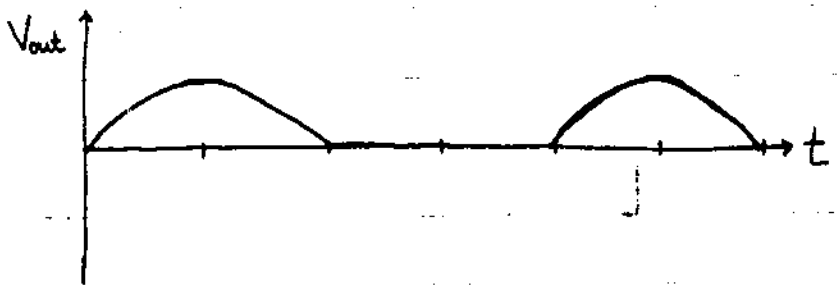


Kirchhoffs spenningsregel: $V_{in} = V_d + V_R$

$$V_d = \begin{cases} 0 & \text{hvis } V_{in} > 0 \\ V_{in} & \text{hvis } V_{in} < 0 \quad (I = 0) \end{cases}$$

$$V_{out} = V_R = RI = \begin{cases} V_{in} & \text{hvis } V_{in} > 0 \\ 0 & \text{hvis } V_{in} < 0 \end{cases}$$





"Halvbølge likeretter"
("Half-wave rectifier")

Hlt 26.03.03