Equation Sheet

	pn Junction and Diodes	
Quantity	**Relationship**	**Notes, Constants and Parameters for Intrinsic Si @ 290 K**
Diffusion current density (A·cm^{-2})	$J_p = -qD_p \frac{dp}{dx}$ $J_n = qD_n \frac{dn}{dx}$	$q = 1.6 \times 10^{-19}$C $D_p = 11.5\ cm^2 \cdot s^{-1}$ $D_n = 34\ cm^2 \cdot s^{-1}$
Drift current density (A·cm^{-2})	$J_{drift} = q(p\mu_p + n\mu_n)E = \sigma E$	$\mu_p = 460\ cm^2 \cdot V^{-1} \cdot s^{-1}$ $\mu_n = 1360\ cm^2 \cdot V^{-1} \cdot s^{-1}$
Conductivity (Ω·cm)$^{-1}$	$\sigma = q(p\mu_p + n\mu_n)$	
Resistivity (Ω·cm)	$\rho = \frac{1}{\sigma} = \frac{1}{q(p\mu_p + n\mu_n)}$	μ_p and μ_n decrease with increase in doping concentration
Ohm's Law (point form)	$J = \sigma E = E/\rho$	
Relationship between mobility and diffusivity	$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$	$V_T = kT/q \cong 25$ mV
Carrier concentration in n-type silicon (cm^{-3})	$n_{no} \cong N_D$ $p_{no} = n_i^2/N_D$	
Carrier concentration in p-type silicon (cm^{-3})	$p_{po} \cong N_A$ $n_{po} = n_i^2/N_A$	
Junction built-in voltage	$V_o = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$	
Width of depletion region (cm)	$\frac{x_n}{x_p} = \frac{N_A}{N_D}$ $W = x_p + x_n$ $= \sqrt{\frac{2\epsilon_{Si}}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(V_o + V_R)}$	$\epsilon_{Si} = 11.7\epsilon_0$ $\epsilon_0 = 8.854 \times 10^{-14}$ F/cm
Charge stored in depletion layer (C)	$Q_J = q\frac{N_A N_D}{N_A + N_D}AW$	
Forward current (A)	$I = I_p + I_n$ $I_p = qAn_i^2 \frac{D_p}{L_p N_D}\left(e^{\frac{V_D}{nV_T}} - 1\right)$ $I_n = qAn_i^2 \frac{D_n}{L_n N_A}\left(e^{\frac{V_D}{nV_T}} - 1\right)$	
Saturation current (A)	$I_S = qAn_i^2\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right)$	
i-v relationship	$I_D = I_S(e^{V_D/nV_T} - 1)$	

Material	m_n^*/m_o (-)	m_p^*/m_o (-)	E_G (eV)	μ_n, μ_p (cm^2·V^{-1}·s^{-1})	D_n, D_p (cm^2·s^{-1})	N_C, N_V (cm^{-3})	Lattice constant (Å)	atoms·cm^{-3}
Si	1.18	0.81	1.12	1360 460	34 11.5	$3.2 \cdot 10^{19}$ $1.8 \cdot 10^{19}$	5.431	$5.0 \cdot 10^{22}$
Ge	0.55	0.36	0.66	3900 1900	97.5 47.5	$1.0 \cdot 10^{19}$ $5.4 \cdot 10^{18}$	5.646	$4.4 \cdot 10^{22}$
GaAs	0.066	0.52	1.42	8000 320	200 8.0	$4.2 \cdot 10^{17}$ $9.5 \cdot 10^{18}$	5.654	$4.42 \cdot 10^{22}$

Equation Sheet

	Semiconductor Physics	
Quantity	**Relationship**	**Notes, Constants and Parameters**
Density of States and Fermi Function	$g_c(E) = \frac{m_n^{*\,3/2}\sqrt{2(E-E_C)}}{\pi^2\hbar^3}$, $E \geq E_C$ $g_v(E) = \frac{m_p^{*\,3/2}\sqrt{2(E_v-E)}}{\pi^2\hbar^3}$, $E \leq E_V$ $f(E) = \frac{1}{1+e^{(E-E_F)/kT}}$	
Carrier Concentrations	$n = \int_{E_C}^{\infty} g_C(E)f(E)dE$ $p = \int_0^{E_V} g_V(E)(1-f(E))dE$	
Carrier Concentrations, Effective Density of States	$n = N_C e^{-(E_c-E_F)/kT}$ $n = n_i e^{(E_F-E_i)/kT}$ $p = N_V e^{-(E_F-E_V)/kT}$ $p = n_i e^{(E_i-E_F)/kT}$ $N_{C,V} = 2\left[\frac{m_{n,p}^* kT}{2\pi\hbar^2}\right]^{3/2}$	assumes nondegenerate $E_V + 3kT \leq E_F \leq E_C - 3kT$
n_i, n, np Product, and Charge Neutrality	$n_i = \sqrt{N_C N_V} e^{-E_G/2kT}$ $np = n_i^2$ $0 = p - n + N_D - N_A$ $n = \frac{N_D-N_A}{2} + \left[\left(\frac{N_D-N_A}{2}\right)^2 + n_i^2\right]^{1/2}$	
Carrier concentration in intrinsic Si (cm^{-3})	$n_i = BT^{3/2}\, e^{-E_g/2kT}$	$B = 7.3 \times 10^{15} cm^{-3} K^{-\frac{3}{2}}$ $E_g = 1.12$ eV $k = 8.62 \times 10^{-5} \frac{eV}{K}$ $n_i = 1.5 \times 10^{10}\ cm^{-3*}$
Fermi Level Relationships	$E_F = E_i + kT * \ln\left(\frac{N_D}{n_i}\right)$ n type $E_F = E_i - kT * \ln\left(\frac{N_A}{n_i}\right)$ p type $E_i = \frac{E_C+E_V}{2} + \frac{3}{4}kT \cdot \ln\left(\frac{m_p^*}{m_n^*}\right)$	
Equations of State	$\frac{\partial \Delta p_n}{\partial t} = D_p \frac{\partial^2 \Delta p_n}{\partial x^2} - \frac{\Delta p_n}{\tau_p} + G_L$ $\frac{\partial \Delta n_p}{\partial t} = D_n \frac{\partial^2 \Delta n}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$ $p_n(x) = p_{no} + p_{no}\left(e^{V_A/V_T} - 1\right)e^{(-x+x_n)/L_p}$ $n_p(x) = n_{po} + n_{po}\left(e^{V_A/V_T} - 1\right)e^{(x+x_p)/L_n}$	$\frac{\partial \Delta p_n}{\partial t} = \frac{\partial \Delta n_p}{\partial t} = 0$ steady state $G_L = 0$ no light
Minority Carrier Diffusion Length (cm)	$L_{n,p} = \sqrt{D_{n,p}\tau_{n,p}}$	$\tau_{n,p} = 1$ ns to 10^4 ns $L_{n,p} = 1$ μm to 100 μm

*This number works out using T=300 K throughout, rather than kT = 25 meV or T=290 K.