Problem 5.2

This is about diffusion. Part a) uses error function statistics, reflecting a constant supply of source material, and part b) uses Gaussian (normal) distribution as appropriate when the source material is being depleted by the diffusion.

a) $N(x) = N_o erfc\left(\frac{x}{2\sqrt{Dt}}\right)$

$$\frac{N(x)}{N_o} = erfc\left(\frac{x}{0.147}\right)$$

The form above lines up nicely with the curves on p 242. Just pick *x* to be a nice multiple of 0.147, and pick the N/N_o value off the chart, and adjust it to find *N(x)*, as in the chart below. The junction occurs where *N(x)* equals the initial wafer doping of $5*10^{16}$.

x (μm)	*u*	erfc *u*	*N(x)*
0.0735	0.5	0.47	$2.4*10^{20}$
0.1470	1.0	0.16	$8.0*10^{19}$
0.2205	1.5	0.033	$1.7*10^{19}$
0.2940	2.0	0.0048	$2.4*10^{18}$
0.3675	2.5	0.0004	$2.0*10^{17}$
0.4410	3.0	0.000023	$1.2*10^{16}$

$5*10^{16}$ is between $2*10^{17}$ and $1.2*10^{16}$, indicating a junction at or near 0.4μm.

b) $N(x) = \frac{N_s}{\sqrt{\pi}\sqrt{Dt}} e^{-\left(\frac{x}{2\sqrt{Dt}}\right)^2} = \frac{N_s}{0.1302} e^{-\left(\frac{x}{0.147}\right)^2}$

Now do the same thing you did in part a) which is to pick values of x that allow interpolation from the graph and subsequent computation of *N(x).*

x (μm)	*u*	Exp(- u^2)	*N(x)*
0.0735	0.5	0.78	$3.0*10^{18}$
0.1470	1.0	0.37	$1.4*10^{18}$
0.2205	1.5	0.105	$4.0*10^{17}$
0.2940	2.0	0.018	$6.9*10^{16}$
0.3675	2.5	0.0019	$7.3*10^{15}$

$x_j = 0.3 \mu m$ this time.

Problem 5.3

How long will it take to form a 1 micron deep junction in p-type Si with an unlimited P source at 1000°C?

$$N = N_o * erfc\left(\frac{x}{2\sqrt{D*t}}\right)$$

N = 2*10^{16} atoms/cm^3(same as acceptor concentration, to achieve junction)
N_o = 10^{21} atoms/cm^3 (from App VII, P at 1000°C)
x = 10^{-4} cm (problem statement)
D = 3*10^{-14} cm^2/s (from App VIII, or from Problem 5.2, since D is same for P and B)

$$2*10^{16} = 10^{21} * erfc\left(\frac{10^{-4}}{2\sqrt{3*10^{14}*t}}\right)$$

The value for the argument of the error function can be read from Figure P5-2 to be 3.0 when the Y value is set at 2*10^{16}/10^{21}=2*10^{-5}.

Solving $3.0 = \left(\frac{10^{-4}}{2\sqrt{3*10^{14}*t}}\right)$ for t yields our time to diffuse to be 9260 seconds.

Problem 5-9

From (3-25 a and b)

$$E_{ip} - E_F = kT*\ln\frac{p_p}{n_i} = 0.0259eV*\ln\frac{10^{17}cm^{-3}}{1.5*10^{10}cm^{-3}} = 0.407eV$$

$$E_F - E_{in} = kT*\ln\frac{n_n}{n_i} = 0.0259eV*\ln\frac{10^{16}cm^{-3}}{1.5*10^{10}cm^{-3}} = 0.347eV$$

a) Draw the diagram and read $q*V_o$ = 0.407 + 0.347 = 0.754 eV

From (5-8)

b) $q*V_o = kT*\ln\frac{N_a*N_d}{n_i^2} = 0.0259\,eV*\ln\frac{10^{17}cm^{-3}*10^{16}cm^{-3}}{\left(1.5*10^{10}cm^{-3}\right)^2} = 0.754\,eV$

Problem 5-12

Simplifying (5-36) for p+n junction (n_p and the -1 term are insignificant)

$I = qA\frac{D_p}{L_p}p_n e^{qV/kT}$ and $p_n = \frac{n_i^2}{n_n}$ and $L_p = \sqrt{D_p \tau_p}$, plug and chug to $I = 0.55\mu A$

Problem 5-19

$N_a = 10^{15}$ cm^{-3} and $N_d = 10^{17}$ cm^{-3}

a) Find the built in potential, V_o.

$$V_o = \frac{kT}{q}\ln\frac{N_a N_d}{n_i^2} = 0.0259\ln\frac{10^{32}}{2.25*10^{20}} = 0.7V$$

b) Find W at zero bias.

$$W = \sqrt{\frac{2\in_s V_o}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)} = \sqrt{\frac{2*8.85*10^{-14}*11.8*0.7}{1.6*10^{-19}}\left(\frac{10^{15}+10^{17}}{10^{32}}\right)} = 0.96\mu m$$

c) Find I at $V_F = 0.5\ V$, given μ_n, μ_p, τ_n and τ_p

$D_n = \mu_n\left(\frac{kT}{q}\right)$ and $D_p = \mu_p\left(\frac{kT}{q}\right)$ = 38.9 cm^2/s and 11.7 cm^2/s respectively.

$L = \sqrt{D*\tau}$ = 0.31 cm and 0.17 cm for n and p respectively.

$$J_o = qn_i^2\left(\frac{D_p}{N_d L_p} + \frac{D_n}{N_a L_n}\right) = 1.6*10^{-19}*2.25*10^{20}\left(\frac{11.7}{10^{17}*0.17} + \frac{38.9}{10^{15}*0.31}\right)$$

$$J_o = 4.5*10^{-12}C/cm^2s$$

$$I = AJ_o\left(e^{qV/kT} - 1\right) = 10^{-3}cm*4.5*10^{-12}C/cm^2s\left(e^{0.7/0.026} - 1\right) = 2.2*10^{-3}A$$