EECS170A Fall 2004 **2nd Midterm Exam** Name:__________________________

11-09-2004 ID no.:__________________________

Sec.B: Peter Burke 3:30 to 4:50 pm

1A	1B	2	3A	3B	3C	3D	3E	Total
/15	/15	/20	/10	/10	/10	/10	/10	/100

THREE PROBLEMS TOTAL.

DO NOT BEGIN THE EXAM UNTIL YOU ARE TOLD TO DO SO.

PROBLEM ONE: (30 points)

1) For a piece of Si at 300 K, $N_D = 10^{17}$ cm^{-3}:

   a. Find the mobility μ_n of electrons to within 10% (15 points)

      μ_n = 801 cm^2/V-s (from the graph in book, figure 3.5)
      Accepted answers: 721 – 881 cm^2/V-s

   b. Find the diffusion constant D_N of electrons to within 10% (15 points)

      $D_N = \mu_n kT/q$
      = (801 cm^2/V-s)(.0259V)
      = 20.7 cm^2/s

PROBLEM TWO: (20 points)

Some baseline temperatures in the three temperature scales:

temperature	kelvins	degrees Celsius	degrees Fahrenheit
symbol	**K**	**°C**	**°F**
boiling point of water	373.15	100.	212.
melting point of ice	273.15	0.	32.
absolute zero	0.	-273.15	-459.67

2) A p-n diode is reverse biased at – 1 V and cooled to the temperature of the melting point of ice (T = 273 K). At that temperature, the current is 1 pA.

The diode is now put into a pot of boiling water, so that its temperature is 373 K. What is the current now, assuming the voltage is still – 1 V?

This problem cannot be solved exactly, since N_A and N_D are not given.
Therefore, and exact solution will not be required to get full credit on this problem.

Generally speaking, there are 2 ways to do this problem:
Use lecture notes, or use book.

<u>METHOD I: USE LECTURE NOTES</u>

In class we showed the

$$I(V_A) = (\text{constant}) e^{-\frac{qV_{bi}}{k_B T}} \left(e^{-\frac{qV_A}{k_B T}} - 1 \right)$$

At V_A=-1 V,

$$\left(e^{-\frac{qV_A}{k_B T}} - 1 \right) \approx 1$$

for T=273 K and T = 373 K.

Therefore, $I(V_A = -1V) \approx -(\text{constant}) e^{-\frac{qV_{bi}}{k_B T}}$

Assuming the constant is independent of temperature (not exactly true but we didn't cover in lecture), we have:

$$\frac{I(V_A=-1V)\big|_{273K}}{I(V_A=-1V)\big|_{373K}} = \frac{-(\text{constant})e^{-\frac{qV_{bi}}{k_B 273K}}}{-(\text{constant})e^{-\frac{qV_{bi}}{k_B 373K}}} = \frac{e^{-\frac{qV_{bi}}{k_B 273K}}}{e^{-\frac{qV_{bi}}{k_B 373K}}} = e^{e^{-\frac{qV_{bi}}{k_B 273K}+\frac{qV_{bi}}{k_B 373K}}}$$

Now, V_{bi} is not given so quantitatively this is as far as you can go.
But a typical value of V_{bi} is 0.5 V. So for a typical value:

$$\frac{I(V_A=-1V)\big|_{273K}}{I(V_A=-1V)\big|_{373K}} = e^{e^{-\frac{q(0.5V)}{k_B 273K}+\frac{q(0.5V)}{k_B 373K}}} = e^{-21.23+15} = e^{-5.75} = 0.003$$

So

$$I(V_A=-1V)\big|_{373K} = \frac{I(V_A=-1V)\big|_{273K}}{0.003} = 333pA$$

METHOD II: USE BOOK

Book eq. 6.29

$$I(V_A) = I_0\left(e^{-\frac{qV_A}{k_B T}} - 1\right)$$

At V_A=-1 V,

$$\left(e^{-\frac{qV_A}{k_B T}} - 1\right) \approx 1$$

for T=273 K and T = 373 K.
Therefore, $I(V_A=-1V) \approx I_0$
Book eq. 6.30

$$* \; I_0 = qAn_i^2\left(\frac{D_N}{L_N}\frac{1}{N_A} + \frac{D_p}{L_p}\frac{1}{N_D}\right)$$

q,A, N_A, N_D independent of temperature.
Book figure 2.20:
n_i (T=273 K) = 10^9 cm^{-3}
n_i (T=373 K)= 10^{12}cm^{-3}

$$\frac{D_N}{L_N} = \frac{D_N}{\sqrt{D_N \tau_n}} = \frac{\sqrt{D_N}}{\sqrt{\tau_n}}$$

Approximately, τ_n independent of temperature.
By Einstein (book eqn. 3.25)

$$\sqrt{D_N} = \sqrt{\frac{k_B T \mu_n}{q}}$$

μ_n depends on temperature, as per book figure 3.7: μ_n decreases with temperature in a way that depends on N_A, N_D.

The most it decreases by is about a factor of 2. So $\sqrt{D_N}$ changes some with temperature, but not by more than a factor of 10.

Similar arguments hold for $\sqrt{D_P}$

So the factor in parenthesis in equation * above changes by a small amount.

However, the n_i^2 factor changes by a large amount, and this dominates.

So if we neglected the factor in parentheses we have:

$$\frac{I(V_A=-1V)\big|_{273K}}{I(V_A=-1V)\big|_{373K}} = \frac{I_0\big|_{273K}}{I_0\big|_{373K}} = \frac{n_i^2\big|_{273K}}{n_i^2\big|_{373K}} = \frac{10^{18}}{10^{24}} = 10^{-6}$$

So

$$I(V_A=-1V)\big|_{373K} = \frac{I(V_A=-1V)\big|_{273K}}{0.001} = 10^6\,pA = 1\mu A$$

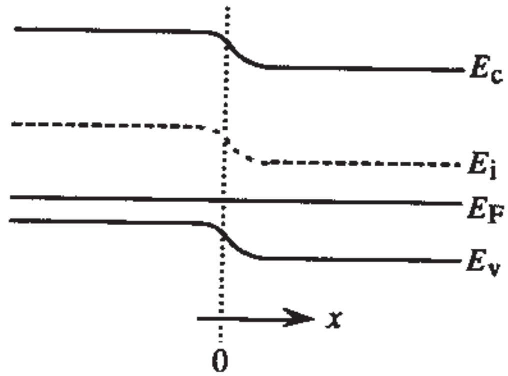
Using either method, the conclusion is that the current at 373 K is much larger than the current at 273 K for reverse bias, by a large factor.

PROBLEM THREE: (50 points)

Came right out of book (chapter 3 problem 5.3). Solution set from author follows.

5.3

(a) Because $N_{A1} > N_{A2}$ and $p = n_i \exp[(E_i - E_F)/kT] \cong N_A$ far from the junction, it follows that $(E_i - E_F)_{x<0} > (E_i - E_F)_{x>0}$. The energy band diagram must therefore be of the form



(b) Given that the dopings are nondegenerate, the same development leading to Eq. (5.10) can be employed, except

$$n(x_n) \cong n_i^2/N_{A2}$$

$$n(-x_p) \cong n_i^2/N_{A1}$$

which when substituted into Eq. (5.8) yields

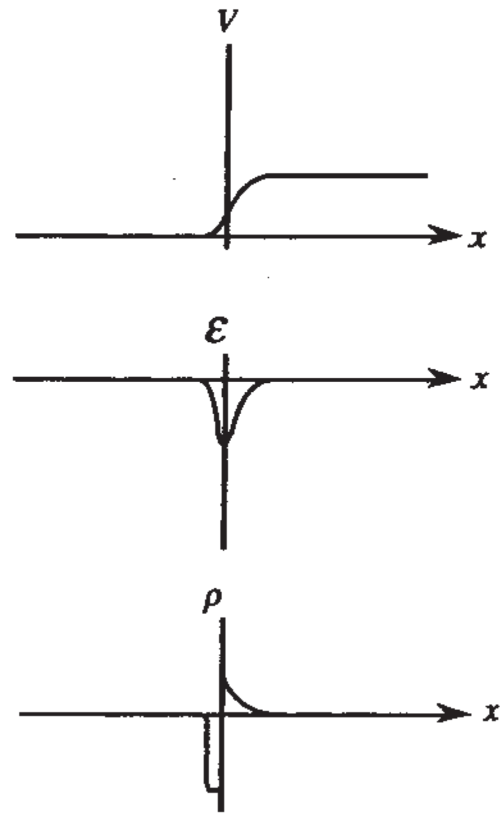
$$\boxed{V_{bi} = \frac{kT}{q}\ln\left(\frac{N_{A1}}{N_{A2}}\right)}$$

Alternatively, one can write

$$V_{bi} = \frac{1}{q}\left[E_i(-\infty) - E_i(+\infty)\right] = \frac{1}{q}\left[(E_i - E_F)_{p1\text{-side}} - (E_i - E_F)_{p2\text{-side}}\right]$$

$$= \frac{1}{q}\left[kT\ln(N_{A1}/n_i) - kT\ln(N_{A2}/n_i)\right] = \frac{kT}{q}\ln(N_{A1}/N_{A2})$$

Note that, as must be the case, $V_{bi} \to 0$ if $N_{A1} = N_{A2}$.



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