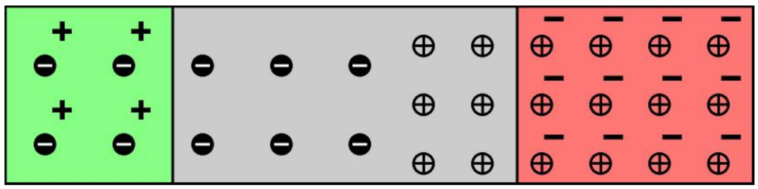
3 Contact Potential

Name:____________________________

In-Class Problems

(1) Draw the two blocks of semiconductor shown below (you don't need to draw all the charges inside, just 1 colored rectangle for each block. Draw it WIDE and higher up on the board, as you will need to draw underneath it too.



(a) label where the two blocks were joined with a black vertical line.

(b) label each region as either: 'Phosphorus atoms and free carriers ' / 'Boron atoms and free carriers' / 'Boron atoms only' / 'Phosphorous atoms only'

(c) label locations where you get 'maximum E-field' and 'zero E-field' and make sure you understand why.

(d) draw a band-diagram underneath this, extending vertical dotted lines down for the edges of the depletion region, and extending down the vertical line for where the blocks were, such that they all go through your band-diagram. Label Ec/Ev/Ef on the diagram. Make sure EVERYTHING in the diagram represents un-equal dopings, including the Fermi-level distances from the bands.

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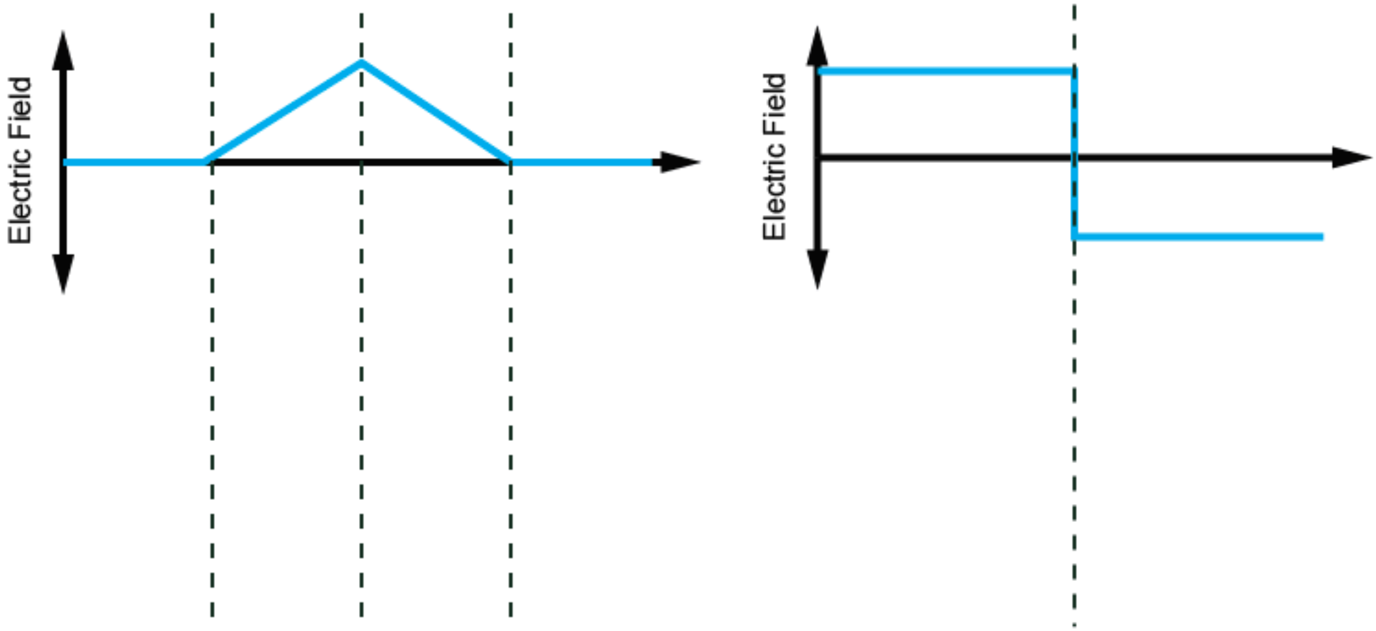
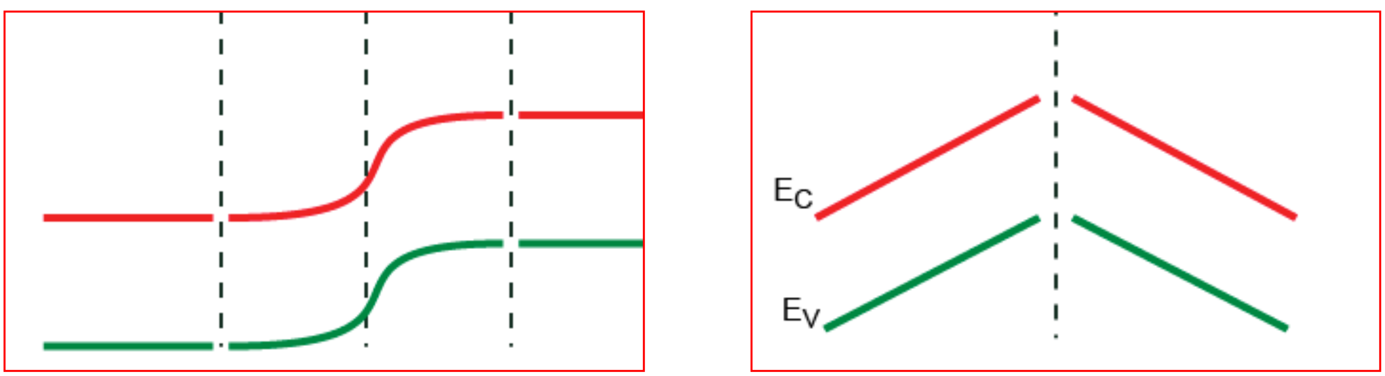
(2) E-field causes band diagrams to have slope! Anytime you have E-field, you know it means the bands must bend! Redraw each of these E-field plots on the board, and below the E-field plots draw the corresponding band diagrams (don't worry about the Ef or dopings, just plot the conduction and valence bands).

To help solve this problem, use the electrons=water and holes=bubbles analogy and think how they each should move (left or right) in the E-field. Assume the E-field is measured in the direction from left to right. Remember, higher E-field should make the bands slope steeper! (postive E-field = positive bands slope / negative E-field = negative bands slope).



Answer:



(3) Questions related to potential across a diode…

(a) Calculate the total amount of band-bending (energy, eV) that would be achieved for a PN junction, in units of eV, for a diode that is doped 10^{17}/cc p-type and 10^{15}/cc n-type. *Hint, calculate for volts, then change it to units of eV. Is simple, for example 1 V will turn into 1 eV. Another hint, at 300K thermal voltage is always 0.0259 V, so you don't need to calculate that part of the equation.*

Make sure you get comfortable when you need to multiply by e in just the units to make eV. See below, q is just moved to the other side of the equation (and listed as 'e'). Some times you have to actually multiply by $1.6\text{x}10^{-19}$ C (like when calculating drift current). Students make this mistake on tests all the time and it throws the answer off huge! Be careful!

$$V(volts) = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2}$$

$$E(eV) = kT \ln \frac{N_A N_D}{n_i^2} = 0.0259 \ln \frac{10^{32}}{(1.5 \times 10^{10})^2} = 0.659 eV$$

(b) [5 pts] On what side would most of the most of the depletion width occur?

Most of the depletion occurs on the lightly doped side which is the n-type side. The lightly doped side has to deplete more deeply to uncover the same amount of charge.

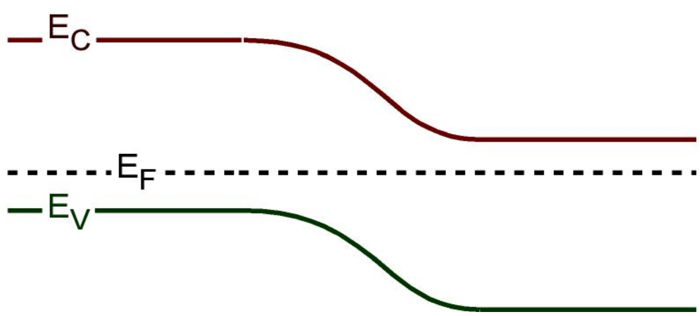
(c) [5 pts] If +0.3 V is added to the n-side while the p-side is grounded, what will be the new total amount of band-bending (in eV)? We have not done this in class, but just think about it… answer is simple (think how bands would bend).

0.659 eV + 0.3 eV = 0.959 eV. That is reverse bias, we will learn more about it in Lecture 4.

(c) A diode has internal contact potential. If you hooked a diode up w/ a wire loop to connect the n and p-sides with the wire, would the internal voltage cause current to continue to flow through the wire? ★

No. How could it? Put a AA battery a shoe box (internal potential) and attach wires to the outside of the shoe-box. No current either right?

(4) Draw the band shown below and then:



(a) add electrons and holes where you think they should be, and try to show the concentrations you expect (for example, maybe 10-12 carriers for majority carriers, and may only 2-3 for minority carriers).

(b) draw with a line-path and arrow-head at the end, the starting point, path, and destination for electron drift current
(c) draw with a line-path and arrow-head at the end, the starting point, path, and destination for electron diffusion current
(d) draw with a line-path and arrow-head at the end, the starting point, path, and destination for hole drift current
(e) draw with a line-path and arrow-head at the end, the starting point, path, and destination for hole diffusion current ★

(5) Now, a repeat from last week because this is very important, again, figure out how a diode works on your own before I even teach you! A diode is rectifying, meaning it gives you very small (nearly zero) current in one direction of voltage polarity, and large current in the other direction of voltage polarity.

(a) for the case of negative voltage applied to the p-side and the n-side grounded, re-draw the conduction and valence bands (don't worry about drawing the Fermi level). Then draw and label the resulting current as dominated by drift or diffusion (only one will dominate) and if it is large or small (think of number of carriers feeding the resulting current, are they majority or minority carriers?).

(b) for the case of positive voltage applied to the p-side and the n-side grounded, re-draw the conduction and valence bands (don't worry about drawing the Fermi level). Then draw and label the resulting current as dominated by drift or diffusion (only one will dominate) and if it is large or small (think of number of carriers feeding the resulting current, are they majority or minority carriers?).

(6) The drift current for a diode at thermal equilibrium originates from (choose one of the following):

_X_ minority carriers that are thermally generated NEAR the depletion region edge and swept across by E-field

__ majority carriers that are thermally generated NEAR the depletion region edge and swept across by E-field

__ minority carriers that are from dopants NEAR the depletion region edge and swept across by E-field

__ majority carriers that are from dopants NEAR the depletion region edge and swept across by E-field

(7) Some review… A slab of semiconductor with a mobility of 1000 (cm/s)/(V/cm) or cm^2/V-s, is setup at steady state to have electrons injected at one side and removed from the other side such that on one side there are 10^{17} electrons and on the other side there are 10^7 electrons. Assume the semiconductor slab is 0.01 cm long (100 μm). Calculate the resulting diffusion current density (A/cm^2). Reminder, thermal voltage is 0.0259 V at 300K.

Note! The equations you will need is found below in equation 8.

Do this as a simple rise over run derivative problem. The distance (or run) is dx (see below). The rise is 10^{17} minus 10^{10} which is basically just 10^{17}.

dN(x) = 10^{17} /cc

dx = 0.01 cm

q= 1.6×10^{-19} C

Dp= 1000 cm^2/V-s, x 0.0259 V = 25.9 cm^2/s

Therefore: J= q*Dp*dN(x)/dx = 41 A/cm^2

(8) Some more review. Drift and diffusion currents! Example equations below are for n-type semiconductor.

$$J_n(drift) = q\mu_n n(x)\ \mathrm{E}(x) = q\frac{(cm/s)}{(V/cm)}(1/cm^3)(V/cm)$$

$$J_n(diffusion) = qD_n\frac{dn(x)}{dx} = q(cm^2/s)(1/cm^4)$$

$$D_n = \mu_n kT/q$$

(a) which type of current requires that the particles have charge *in order to move.*

X drift. __ diffusion. __ both. __ neither. Drift is driven by E-field, so you need charge!

(b) which type of current requires a concentration gradient of the particle distribution *in order to move.*

__ drift. X diffusion. __ both. __ neither. Diffusion is driven by a concentration gradient!

(c) why do we have a 'q' in the front of both equations? One sentence max.

Well, current has units of C/s, so we need to know how much charge we have C (in Coulombs). *In this class, q is the charge of 1 electron, 1.6E-19 C (a hole is the absence of an electron, has same charge magnitude but opposite sign).*

(d) what is mobility, basically? One sentence max. Look at the units to create your definition!

How fast the carrier moves (velocity) for a given amount of electric field (voltage applied per unit distance).

(e) for diffusion coefficient $D_n = \mu_n kT/q$, why do we need the kT/q? One sentence max.

kT is eV, divided by q (which is charge e) is gives us just V, which is 'thermal' voltage. *This should make sense, higher temperature gives us greater diffusion current (higher temperature, gives us higher thermal voltage kT/q, with* *units of V, diffusion is not driven by voltage, it is driven by things bumping into each other and spreading out, which is thermally driven).* Thermal voltage and mobility together, then tell us how strongly things can potentially diffuse!

(f) if you create an excess of electrons at some point (delta function) in a slab of semiconductor material they will diffuse away, what concentration profile (equation) mathematically represents the excess carrier concentration as a function of distance? See the slides for lecture 2…

$n(x) = \Delta n\, e^{-x/L_n}$ *The exponential decrease is because the excess carriers are recombining as they diffuse away from where they started (disappearing with distance away from the excess).*