Answer Set 3
Physics 240B

1. a) $\mu_p = -0.5755$ eV and $\mu_n = 0.5897$ eV. Both are shifted in the SAME direction from the gap center because of the band asymmetry, and they shift in OPPOSITE directions because of the dopants. See answer set 1.

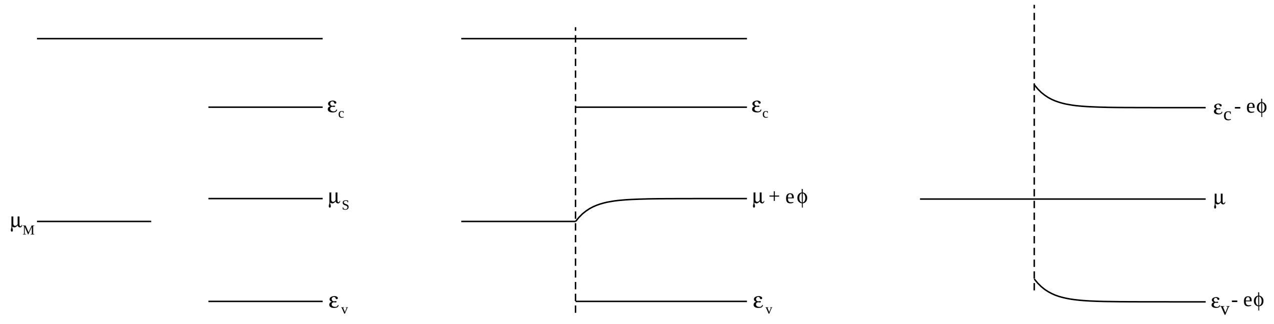
b) Using A&M (29.18), $d_p = 101\mu$m and $d_n = 25.3\mu$m. These are much larger than typical depletion layer sizes because the dopant concentrations are extremely low.

c) Use A&M (29.3) for n_c and p_v. For n_d and p_a, modify (28.32) and (28.34) by shifting ε_c and ε_v by $-e\phi$, as is done in (29.3). The charge density is $\rho = -e*(n_c - p_v + N_a - p_a)$ on the p side, and $\rho = -e*(n_c - p_v - N_d + n_d)$ on the n side. In the following table, the concentrations are all per cubic centimeter, and ρ is in esu/cm^3.

position	n_c	p_v	p_a (p-side) or n_d (n-side)	ρ
$-0.9d_p$	4.1×10^{-8}	1.01×10^{11}	2.2×10^{4}	0.27
$-0.75d_p$	2.7×10^{-7}	1.55×10^{10}	3400	-40.5
$-0.5d_p$	2.0×10^{-4}	12.07×10^{7}	4.5	-48.0
$-0.1d_p$	8.1×10^{4}	0.051	1.1×10^{-8}	-48.0
$0.1d_n$	3.41×10^{8}	1.2×10^{-5}	47	192
$0.5d_n$	4.71×10^{10}	8.8×10^{-8}	6400	169
$0.75d_n$	2.43×10^{11}	1.7×10^{-8}	3.3×10^{4}	75.3
$0.9d_n$	3.82×10^{11}	1.1×10^{-8}	5.2×10^{4}	8.7

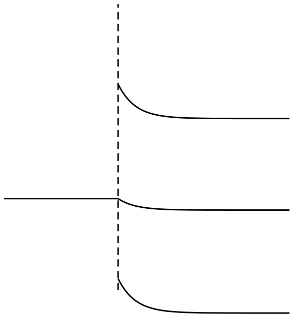
(The positive sign for the first entry in the last column comes from roundoff errors, which can be a major hassle when dealing with exponentials.) Some things to notice: n_c and p_v fall well below their homogeneous values in the depletion layer, justifying the name. p_a and n_d are very small compared to N_a and N_d even outside the depletion layer (so they don't affect the first several digits of ρ), but they decrease to nearly zero within the layer.

2.

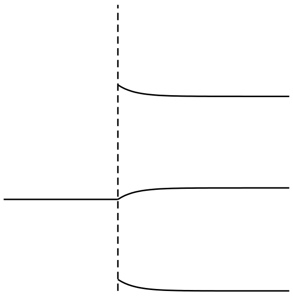


a) far away b) crystal energies only b) crystal plus field

c) First, remember that hole energy increases in the DOWNWARD direction on all these graphs. On the metal side, there are many holes (since the top part of the band is empty), but only a tiny fraction of these have enough energy to make it to the semiconductor's valence band. On the semiconductor side, there are fewer holes, but those present can flow freely into the metal. You may be bothered by this argument because the semiconductor is p-type, and hence does have some appreciable number of holes, albeit less than the metal. In particular, what happens as the dopant density N_a increases? Well, in that case μ_s gets pulled down closer to the valence band until eventually the condition on the work functions is violated and the bands start to curve the other way, creating a barrier to hole motion.



d) M more negative than S



e) M more positive than S

Note that relative voltages at the interface don't change. Nor do the relative values of μ, ε_c, and ε_v far from the interface. (My pictures are for an applied voltage with half the magnitude of the original potential difference that gets set up from the difference in μ's.)

d) The barrier for holes to travel from metal to semiconductor increases, so flow in that direction goes down. (The part of the barrier that changes is within the semiconductor, not right at the M/S interface—there's now a bigger energy difference between the hole pocket at the edge of the semiconductor and the bulk hole states farther in.) The flow from semiconductor to metal, which is limited by the number of holes in the semiconductor, increases as the bias voltage drives more holes towards the junction on the semiconductor side. This gives a net current from the semiconductor to the metal that increases with voltage.

e) Now the voltage pushes holes in the semiconductor away from the junction, reducing hole flow from semiconductor to metal. The barrier for holes going from metal to semiconductor decreases, leading to net current in that direction. Again the current grows with voltage. The junction is considered "ohmic," even though the current may not be strictly proportional to voltage.

f) There are few electrons at conduction band energies on either side of the junction, so they don't contribute as much to the total conductivity as the valence band effects.