Closed book, notes, one 8 x 11" sheet of paper is allowed for notes (front and back). Show all work and include units for all numerical answers. Assume all samples are silicon, at room temperature and in equilibrium, unless otherwise stated.

Constants:

\[
\begin{align*}
q &= 1.6 \times 10^{-19} \text{ coulomb} \\
\varepsilon_0 &= 8.85 \times 10^{-12} \text{ F/cm} \\
\hbar &= 6.63 \times 10^{-34} \text{ joule-s} \\
k &= 8.62 \times 10^{-5} \text{ eV/K} \\
m_0 &= 9.11 \times 10^{-31} \text{ kg} \\
1 \text{ Å} &= 10^{-8} \text{ cm} \\
1 \text{ eV} &= 1.6 \times 10^{-19} \text{ joule} \\
c &= 3 \times 10^{10} \text{ cm/s} \\
E_v (\text{Si @ 300K}) &= 1.125 \text{ eV} \\
\varepsilon_0 (\text{Si @ 300K}) &= 10^{10} \text{ cm}^{-2} \\
\mu_v (\text{Si @ 300K}) &= 1200 \text{ cm}^2/\text{V.s} \\
\mu_p (\text{Si @ 300K}) &= 400 \text{ cm}^2/\text{V.s}
\end{align*}
\]

1. (10 pts) The element tungsten (W) has a body-centered cubic structure with a lattice constant of 3.16 Å. What is the distance between nearest neighbor atoms in the tungsten crystal?
3. An electrically isolated, p-type Si bar is doped with $10^{18}$ cm$^{-3}$ acceptor atoms and no donor atoms. The material is being exposed to light, which generates carriers uniformly throughout the material at a rate of $10^{20}$ cm$^{-3}$s$^{-1}$. Assume $D_n = 30$ cm$^2$/s, $D_p = 10$ cm$^2$/s, $\tau = 10^{-6}$ s, and the electric field in the material is negligible.

a) (10 pts) Calculate the excess electron concentration in the bulk (i.e. far from the surface).

b) (10 pts) Calculate the electron concentration at the silicon surface if $S = 2000$ cm/s.
4. A p-type silicon wafer is uniformly doped with both $10^{18}$ cm$^{-3}$ boron atoms and an unknown amount of arsenic. At a temperature of 300 K, its resistivity is 0.01 Ωcm (Assume all the dopants are ionized)

a) (10 points) Estimate the arsenic concentration?

b) (15 pts) What is the difference in energy between the Fermi level and the valence band?
5. The electron concentration in a silicon sample is varies linearly with distance, as shown in the figure below.

\[
\begin{array}{c}
\text{electron conc. (cm}^{-3}\text{)} \\
\hline
0 & 10^{18} & 5 \times 10^{18} \\
L & & \\
\end{array}
\]

a) (10 pts) If the electron diffusion current density is found to be 400 A/cm\(^2\), calculate the length, L, of the sample.

b) (10 pts) If the total current and hole diffusion current densities are negligible, calculate the electric field at \(x = 1.0 \text{ \mu m}\).
3.4. \( \rho = 5 \times 10^{-12} \times 2 \times 10^{-12} = 1 \times 10^{-24} \text{ cm}^3 \)

\[ \rho = 1/(6 \times 10^{-19} \times 2 \times 10^{-14}) = 0.65 \text{ cm}^{-3} \]

\[ 3.5. \quad j = \frac{\rho}{\mu_0} \cdot \frac{\mu_0}{c^2} = \frac{V_0}{c^2} \cdot \text{cm}^{-3} \]

\[ 3.6. \quad j_0(C) = \frac{\mu_0}{\mu_0} \cdot \frac{v}{2} = 3 \times 10^{13} \text{ cm}^{-3} \]

\[ 3.7. \quad \rho(x) = 3 \times 10^{-18} \text{ cm}^{-3} \]

\[ 3.8. \quad i = -\frac{\rho}{\epsilon_0} \frac{\partial \phi}{\partial x} \]

\[ 3.9. \quad i = -\frac{\rho}{\epsilon_0} \frac{1}{L_p} \cdot \frac{v}{2} = 6 \times 10^{-19} \text{ A/cm} \]

\[ 3.10. \quad i = 5 \times 10^{-12} \text{ A/cm} \]

\[ 3.11. \quad i = \frac{B}{\mu_0} \cdot \frac{\mu_0}{\mu_0} \cdot \frac{v}{2} = \frac{6 \times 10^{-19} \text{ cm}^2}{\mu_0} \cdot \frac{1}{L_p} \cdot \text{cm} \]

\[ 3.12. \quad i = 7 \times 10^{-14} \text{ A/cm}^2 \]