VE320 Intro to Semiconductor Devices
Summer 2024 — Problem Set 1
Due: 11:59pm 31st May

1) Consider a particle of mass *m* confined by the following potential:

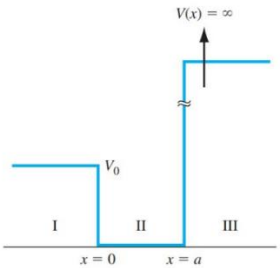
$$V(x) = \begin{cases} \infty & x \le -\frac{L}{2} \\ 0 & -\frac{L}{2} < x < \frac{L}{2} \\ \infty & x \ge \frac{L}{2} \end{cases}$$

a) What is the wave function for $|x| > L/2$?
b) Consider the time independent Schrodinger equation:

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2} + V(x)\psi(x) = E\psi(x)$$

What quantity from classical mechanics do the first and second quantity in the left side of the equation most closely represent?
c) First, independent of the boundary conditions, what is the most general solution that solves the Schrodinger equation above in the region where the potential vanishes.
d) State the boundary conditions that the wave function must satisfy.
e) Derive and normalize expressions for the allowed energies and energy eigenfunctions.
f) Sketch the first three eigenfunctions.

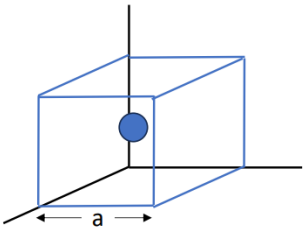
2) Consider the following one-dimensional potential function:



Assume the total energy of an electron is $E < V_0$.
a) Write the wave functions that apply in each region.
b) State the boundary conditions that the wave function must satisfy.
c) Show explicitly why, or why not, the energy levels of the electron are quantized.

3) List and explain at least three phenomena that can't be explained by classical physics but can be explained by quantum physics. You can answer in this form: "classical physics predicts that…., but the contradiction is…., quantum physics solves this problem by…."

4) A lattice with a cubic unit cell as shown below has a single atom positioned at its center.

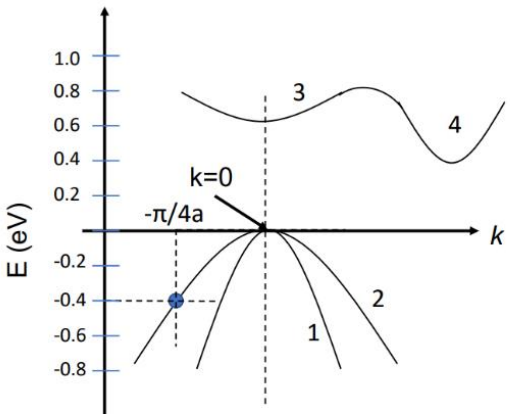


a) Determine the number of atoms per unit volume in the crystal (state your answer in units of a).
b) Determine the number of atoms per unit area on the (110) plane.
c) A direction vector is drawn through the center of the atom in the unit cell. What is the direction vector?

5) From the perspective of energy bands, explain the difference between conductors, semiconductors and insulators. Also explain the reason why metals are conductive while semiconductors are non-conductive at 0K.

6) Briefly explain what is doping and why doping is important in the field of semiconductor. What's the difference between p-type dopant and n-type dopant? List two potential p-type dopants and n-type dopants for silicon.

7) The band structure of a semiconductor is shown below:



a) Is this a direct or indirect band gap semiconductor?
b) Label the conduction band, the valence band and the energy gap on this diagram. What is the value of the energy gap approximately?
c) Compare the magnitude of the effective masses between points 1-2 and points 3-4. Which are electron and which are hole masses?
d) The E-K relationship of a hole is located at the point of the circle on band 2. State the momentum and the kinetic energy of the hole at the point of the circle.
e) Calculate the velocity and effective mass of the hole.