Q1 (a) What is the lattice of Si? **Circle one**
- Face centered cubic
- Body centered cubic
- Diamond lattice

(b) Si atom has 14 electrons as its atomic number is 14. How many electrons are in the outer shell? **Circle one**
- 2
- 4
- 8

Q2. Fig. 17 shows schematically formation of energy bands from discrete levels when atoms coalesce as solid. Four outer electrons of each Si atom become 4N electrons in a solid comprising of N Si atoms. Since each electron needs or occupies an energy level (due to Fermi-Dirac statistics and Pauli’s exclusion principle), we need 4N energy levels to accommodate these electrons when a 3-D solid forms. In Si solid 3s and 3p levels hybridize to form two energy bands which are separated by a gap. These two bands could accommodate 8N electrons (4N each).

(a) Where do the available 4N outer electrons go at zero degree Kelvin? **Circle one**
- In the lower energy (or valence) band
- In the upper (or conduction) energy band.

(b) What happens to the electrons when temperature is raised to \( T = 300 \text{K} \)? **Circle correct ones**
- Equal number of holes in valence band (VB) and electrons in conduction band
- No electrons in VB

Fig. 17 (reproduced below) shows two bands formed at the location marked by double headed arrow (band gap).

Q3 (a) Can there be holes in the top or conduction band? **Circle one**
- Yes
- No

Q. 3(b). In a pure (intrinsic) Si, the intrinsic carrier concentration \( n_i \): **Circle one**
- Increases linearly with temperature
- Does not change
- Increases exponentially

Q. 4 (a) If Si wafer is doped with boron atoms \( 10^{17} \text{ cm}^{-3} \) which are all ionized, what is the electron \( (n_p) \) and hole \( (p_p) \) concentrations. Given \( n_i = 1.5 \times 10^{10} \text{ cm}^{-3} \) at room temperature 300K.

\[
\begin{align*}
 n_p &= \frac{n_i^2}{10^{17}} = \frac{2.5 \times 10^{13}}{10^{17}} = 2.5 \times 10^{3} \\
p_p &= 10^{17} 
\end{align*}
\]

(b) If the Si wafer is doped with phosphorus atom \( 10^{19} \text{ cm}^{-3} \). Find the equilibrium electron \( n_{eq} \) and hole \( p_{eq} \) concentrations at room temperature 300K. Assume all boron atoms to be ionized.

\[
\begin{align*}
 n_{eq} &= \frac{2.5 \times 10^{19}}{10^{17}} = 2.5 \times 10^{3} \\
p_{eq} &= 10^{17}
\end{align*}
\]
Q. 5 (a) The charge neutrality condition in a p-type Si doped (with boron having an ionized acceptor concentration \(N_A^\text{+} \), electron concentration \(n_p \) and hole concentration \(p_n \)) is expressed as \( qN_A^- + qp_n = qn_n \),

What is unknown parameter which needs to be solved in above equation? Circle one.

Fermi level \( E_F \)  
Energy gap  
Temperature

(b) Write the charge neutrality condition for n-Si doped with \(N_D^-\) donors of which \(N_D^\text{+} \) are ionized.

\[
\frac{q}{2}N_D^\text{+} \pm \frac{q}{2}n = q \mu \quad \frac{q}{2}N_D^\text{+} \pm \frac{q}{2}p_n = q \mu_n
\]

Q. 6 The density of states \(N(E)\) [x-axis in figure below] as a function of energy \(E\) (y-axis) in a conduction band is expressed by Eq. 14.

(a) Plot \(N(E)\) for conduction band as a function of energy \(E\).

\[
N(E)dE = \frac{1}{2\pi^2} \left( \frac{2m^*}{\hbar^2} \right)^{3/2} E^{1/2} dE
\]

(b) What is the value of \(f(E)\) representing Fermi-Dirac distribution at \(E=E_F\). Circle one

\[
0 \quad \frac{1}{2} \quad 1
\]

Given: \(f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}\) Fermi-Dirac distribution function.

Q. 7. (a) Electric field \(E\) is related to potential \(\psi\). Circle the correct answer.

\[
E = -\nabla \psi
E = \nabla \psi
\]

(b) The electron concentration is expressed by following two equations:

\[
n = 2 \left[ \frac{2\pi m^* kT}{\hbar^2} \right]^{3/2} \cdot e^{E_F/kt} \quad \text{and} \quad n = N_e e^{E_F/kt}.
\]

What is the value of \(N_e\).

\[
N_e = 2 \left[ \frac{2\pi m^* kT}{\hbar^2} \right]^{3/2}
\]

Q8(a) If the two wafers are joined to form an n-p junction, what will be the built-in voltage \(V_{in}\). Circle the correct expressions.

\[
\frac{kT}{q} \ln \left( \frac{N_A N_D}{n_i^2} \right) \quad \text{OR} \quad \frac{kT}{q} \ln \left( \frac{p_n}{n_i} \right).
\]

8(b) does the built-in voltage change if the doping of n-p junction is changed? Circle one

YES  
NO
Q.9 Semiconductors have more donors (or no acceptors) are called n-type semiconductors as they have more electrons in the conduction band, and semiconductors having more acceptor atoms behave as p-type as they have more holes. Unlike metals, semiconductors consist of both electrons and holes.

The product of electron (n) and hole (p) concentration, under equilibrium, is constant np=n_i^2. n_i in Si at room temperature (T=300K) =1.5x10^{10} cm^{-3}. Assume all donors and acceptors are ionized at 300K.

(a) Find electron concentration in the p-region (n_{po}) and hole concentration in the n-region (p_{no}) of a p⁺-n diode shown in Fig. 6. Here, subscript p refers to the p-region, primary character n refers to n-Si, subscript 'o' is for equilibrium.

Electron concentration in the p-region (n_{po}) =

\[ n_{Po} = \frac{n_i^2}{p_{Po}} = \frac{(1.5 \times 10^{10})^2}{10^{20}} = 2.25 \times 10^3 \text{ cm}^{-3} \]

Hole concentration in the n-region (p_{no})

\[ p_{No} = \frac{n_i^2}{p_{No}} = \frac{(1.5 \times 10^{10})^2}{10^{20}} = 2.25 \times 10^3 \text{ cm}^{-3} \]

(b) Plot the hole and electron concentrations in the p⁺, n regions, and in the junction region for the p⁺-n Si diode of Fig. 6. (Concentration of holes in p-region and electrons in n-region are shown)

Fig. 6 Schematic of a p⁺-n junction under equilibrium.
Q.10. Show that the solution $\psi$ of Schrödinger equation 1 (pages 20-21) is expressed by Eq. 3 for an infinite quantum well for the two boundary conditions $\psi(x=L)=0$ and $\psi(x=0)=0$.

$$\frac{d^2\psi}{dx^2} = -\frac{2mE}{h^2} \psi$$  \hspace{1cm} (1)$$

where $k_x = \frac{2mE}{h^2}$ \hspace{1cm} (2)

$$\psi = Ae^{-ik_xx} + Be^{ik_xx}$$  \hspace{1cm} (3)

$$\frac{d\psi}{dx} = A(-ik_xx)e^{-ik_xx} + B ik_xx e^{ik_xx}$$

$$\frac{d^2\psi}{dx^2} = A(-ik_x)^2 e^{-ik_xx} + B (ik_x)^2 e^{ik_xx}$$

$$= \left(A k_x^2 e^{-ik_xx} + B k_x^2 e^{ik_xx}\right)$$

$$= -k_x^2 \left(A e^{-ik_xx} + B e^{ik_xx}\right)$$

From Eq. 1.

$$\frac{d^2\psi}{dx^2} = -k_x^2 \psi(x)$$

Substituting $k_x^2 = \frac{2mE}{h^2}$

$$\frac{d\psi}{dx} = \frac{-2mE}{h^2} \psi(x)$$

Hence $\psi = Ae^{-ik_xx} + Be^{ik_xx}$ is the solution of Eq. 1.