CHAPTER FOUR

SOLID STATE ELECTRONICS AND SEMICONDUCTOR DEVICES

91. The allowed orbit radii and energy levels of the Bohr atom are given by:

\[ r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m Z e^2} \]

and

\[ W_n = \frac{-m e^4 Z^2}{8 \varepsilon_0^2 h^2 n^2} \]

where \( Z \) is the atomic number, \( e \) and \( m \) are the electron charge and mass respectively, \( h \) is Planck's constant, \( n \) is the principal quantum number for the orbit and \( \varepsilon_0 \) is the permittivity of free space.

Show that these equations may be written as \( r_n = 0.529 n^2 / Z \) angstrom units and \( W_n = -(13.6 Z^2 / n^2) \) eV.

92. (a) What are the first four permissible energy levels for a hydrogen atom?

(b) An electron in a hydrogen atom makes a transition from energy level 2 to the ground state. Determine the energy released by the electron. What is the frequency of the resulting radiation from the atom?

[Ans. (a) -13.6 eV; -3.4 eV; -1.51 eV; -0.85 eV,
(b) 10.2 eV; 2.465 \times 10^{15} \text{ Hz}]"

93. The motion of the fifth electron in the outer shell of a group V impurity atom in a semiconductor may be considered to be a circular orbit around a single positive nuclear charge of \( +e \) and through a material with a dielectric constant of the bulk material.

Show that the electron only requires about 0.1 eV of energy to be freed for conduction in the crystal if the dielectric constant is 11.7. Estimate also the radius of the ground-state orbit and thereby justify the assumption that the electron moves in a medium with the bulk dielectric constant. The lattice constant of the material is 5.42 Å.

[Ans. 6.16 Å]
94. Calculate the velocity of an electron in the ground state of hydrogen. At what fraction of the velocity of light is the electron travelling? Take the velocity of light as $3 \times 10^8$ ms$^{-1}$.

\[ \text{Ans. } 2.19 \times 10^6 \text{ ms}^{-1}, 7.3 \times 10^{-3} \]

95. The resistivity of intrinsic germanium at 300 K is $0.47 \Omega\text{m}$. The electron and hole mobilities in germanium are $0.36 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$ and $0.17 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$ respectively. Calculate from this information the intrinsic density of electrons and holes.

\[ \text{Ans. } 2.5 \times 10^{19} \text{ m}^{-3} \]

96. The material used in Question 95 is doped with antimony impurity atoms so that there is one impurity atom per $10^6$ germanium atoms. Calculate the electron and hole densities at 300 K. It may be assumed that all antimony atoms are ionized at this temperature. The density of germanium atoms is $4.4 \times 10^{28} \text{m}^{-3}$. What is the resistivity of this doped material?

\[ \text{Ans. } 4.4 \times 10^{22} \text{m}^{-3}, 1.42 \times 10^{16} \text{m}^{-3}, 4 \times 10^{-4} \Omega\text{m} \]

97. From the information given in Question 95 determine the diffusion coefficients both for holes and electrons in germanium at 300 K.

\[ \text{Ans. } 4.4 \times 10^{-3} \text{m}^2\text{s}^{-1}, 9.3 \times 10^{-3} \text{m}^2\text{s}^{-1} \]

98. Show that a semiconductor has a minimum conductivity at a given temperature when the electron density $n$ is $n_t \sqrt{\mu_h/\mu_e}$ where $n_t$ is the intrinsic density and $\mu_h$ and $\mu_e$ are the mobilities of holes and electrons respectively. What is the hole density $p$ in this condition?

Find the intrinsic and minimum conductivities for germanium when $n_t = 2.5 \times 10^{19} \text{m}^{-3}$, $\mu_h = 0.19 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$ and $\mu_e = 0.38 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$.

For what values of $n$ and $p$ (other than $n = p = n_t$) does this crystal have a conductivity equal to the intrinsic conductivity?

\[ \text{Ans. } n_t \sqrt{\mu_e/\mu_h}, 2.28 \text{ Sm}^{-1}, 2.12 \text{ Sm}^{-1}, 1.25 \times 10^{19} \text{m}^{-3}, 5 \times 10^{19} \text{m}^{-3} \]

99. A $p$-$n$ junction consists of a region of $p$-type germanium with a conductivity of $10^4 \text{S}$ and a region of $n$-type germanium with a conductivity of $10^2 \text{S}$. The mobilities of electrons and holes in germanium are $0.36 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$ and $0.17 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$ respectively. The intrinsic density of holes and electrons in germanium at 300 K is $2.5 \times 10^{19} \text{m}^{-3}$. Calculate the contact potential that would appear across the junction at 300 K.

\[ \text{Ans. } 0.35 \text{ V} \]