Department of Physics and Astronomy
King Saud University Riyadh

Home assignment # 2 **Physics 570**

Mass of the electron m	$= 9.11 \times 10^{-31}$ kg
Planck's constant h	$= 2\pi \times 1.05 \times 10^{-34}$ Js
elementary charge e	$= 1.60 \times 10^{-19}$ C
one electron volt	$= 1.60 \times 10^{-19}$ J
Boltzmann's constant k_B	$= 1.38 \times 10^{-23}$ JK^{-1}
permittivity of vacuum ε_0	$= 8.85 \times 10^{-12}$ Fm^{-1}
Avogadro's number	$= 6.02 \times 10^{23}$

Q. 1. Theory shows that the density of electrons in the conduction band of a semiconductor (whether intrinsic or extrinsic) is given by

$$n_e = A(m_e T)^{3/2} \exp\left(\frac{\mu - E_C}{k_B T}\right)$$

where μ is the chemical potential of the electrons in the material, E_C is the energy of the bottom of the conduction band, k_B is Boltzmann's constant, T is temperature and m_e is the effective mass of the electrons. The constant A is given by $\frac{1}{4}(2k_B/(\pi\hbar^2))^{3/2}$

The density of holes in the valence band is similarly given by

$$n_h = A(m_h T)^{3/2} \exp\left(\frac{E_V - \mu}{k_B T}\right)$$

where m_h is the effective mass of the holes, and E_V is the energy of the top of the valence band.

i. For an intrinsic semiconductor, show that the chemical potential of the electrons is given by

$$\mu = \frac{1}{2}(E_C + E_V) + \frac{3}{4}k_B T \ln\left(\frac{m_h}{m_e}\right)$$

ii. Calculate the chemical potential of electrons relative to the top of the valence band $(\mu - E_V)$ for intrinsic silicon at 300 K, if E_C-E_V=1.1 eV, and assuming that both m_e and m_h are equal to the mass of a free electron.

iii. If the hole density in a sample of *p*-type silicon is 10^{22} m^{-3}, calculate the chemical potential, relative to the top of the valence band, of the electrons in this material at 300 K.

iv. If a junction is formed between this *p*-type silicon and some intrinsic silicon, which way would electrons initially flow, and why?

Q. 2. Find the relaxation time τ for electrons and holes in the following semiconductors materials whose electrons and holes mobility and their effective mass are given in the table

Name of materials	Electron effective mass	Electron mobility cm^2/V-s	Hole effective mass	Hole mobility cm^2/V-s
In Sb	0.015	800	0.39	450
GaAs	0.066	8000	0.5	300
In As	0.026	30000	0.41	450

Q. 3. Indium antimonide has Eg = 0.023 eV, dielectric constant $\varepsilon = 18$; electron effective mass m_e=0.015. Calculate

a. The donor ionization energy Ed

b. The radius of the ground state orbit

c. At what minimum donor concentration will appreciable overlap effects between the donor orbits of adjacent impurity atoms occur?

Q. 4. In particular semiconductor there are 10^{13} donors /cm^3 with an ionization energy E_d of 1 meV and an effective mass 0.01 m. Estimate the number of conduction electron at 4K and room temperature (300K).

Q. 5. Explain the operation of photovoltaic (PV) cell on the basis of P-N junction. Also discuss the different types of energy loss in solar or PV cell.

Q. 6. The wave function of hydrogen atom in its ground state 1s is $\psi = (\pi a_0^3)^{-1/2} \exp(-r/a_0)$, where $a_0 = 0.529 \times 10^{-8}$ cm. The charge density is $\rho(x,y,z) = -e|\psi|^2$, according to statistical interpretation of wave function. Show that for this state $\langle r^2 \rangle = 3 a_0^2$. and calculate the molar diamagnetic susceptibility of atomic hydrogen is $(-2.36 \times 10^{-6}$ cm^3 / mole).

Q7 Apply the Hund rule to find the ground state of

(a) Eu^{++} $(4f^7 5s^2 p^6)$ (b) Yb^{3+} (c) Tb^{3+} write the answer step by step applying the rules. Find the value of effective Bohr magnetons (p) in each case.

Q.8 Explain Meissner effect. What is the difference between perfect conductors and superconductors. Also show that the perfect conductivity of the material can not explain the Messner effect.

Q.9 What is Type I and Type II superconductors? Explain the term H_{C1} and H_{C2}.