

Ερωτήσεις για στερεά Παραδοση για τις ερωτήσεις 1-26 την 6/12/2016, ενώ για τις ερωτήσεις 27-40 την 9/12/2016

- All quantities characterizing the properties of any solid or liquid depend necessarily but not exclusively on the universal physical constants appearing in one of the following triads:
(a) \hbar, c, m_e (b) \hbar, c, m_p (c) \hbar, e, m_p (d) \hbar, e, m_e
- In an fcc lattice with a being the lattice constant the distance between nearest neighbors is:
(a) $a/\sqrt{3}$ (b) $a/\sqrt{2}$ (c) $a/2$ (d) $a/3$
- In a diamond lattice with a being the lattice constant of the unit cubic cell the distance between nearest neighbors is:
(a) $\sqrt{3}a/4$ (b) $a/\sqrt{6}$ (c) $2a/\sqrt{6}$ (d) $a/4$
- In a solid we define the length r by the relation: $(4\pi/3)r^3 \equiv V/N_a$. In terms of r the density is given by one of the following equation ($\bar{r} \equiv r/a_B$):
(a) $\rho = (2.675A_B/\bar{r}^2) \text{ g/cm}^3$ (b) $(2.675A_B/\bar{r}^3) \text{ g/cm}^3$
(c) $(2.675A_B^2/r^2) \text{ g/cm}^3$ (d) $(2.675A_B/\bar{r}^4) \text{ g/cm}^3$
- In a solid we define the length r by the relation: $(4\pi/3)r^3 \equiv V/N_a$. In terms of r the cohesive energy is given by one of the following equation ($\bar{r} \equiv r/a_B$):
(a) $\varepsilon_c \approx 27.2/\bar{r}^2 \text{ eV}$ (b) $\varepsilon_c \approx 27.2/\bar{r} \text{ eV}$
(c) $\varepsilon_c \approx 27.2/\bar{r}^3 \text{ eV}$ (d) $\varepsilon_c \approx 27.2/\bar{r}^5 \text{ eV}$
- In a solid we define the length r by the relation: $(4\pi/3)r^3 \equiv V/N_a$. In terms of r the bulk modulus B is given by one of the following equation ($\bar{r} \equiv r/a_B$):
(a) $B \approx 175 \times 10^6/\bar{r}^2 \text{ bar}$ (b) $B \approx 175 \times 10^6/\bar{r}^3 \text{ bar}$
(c) $B \approx 175 \times 10^6/\bar{r}^4 \text{ bar}$ (d) $B \approx 175 \times 10^6/\bar{r}^5 \text{ bar}$

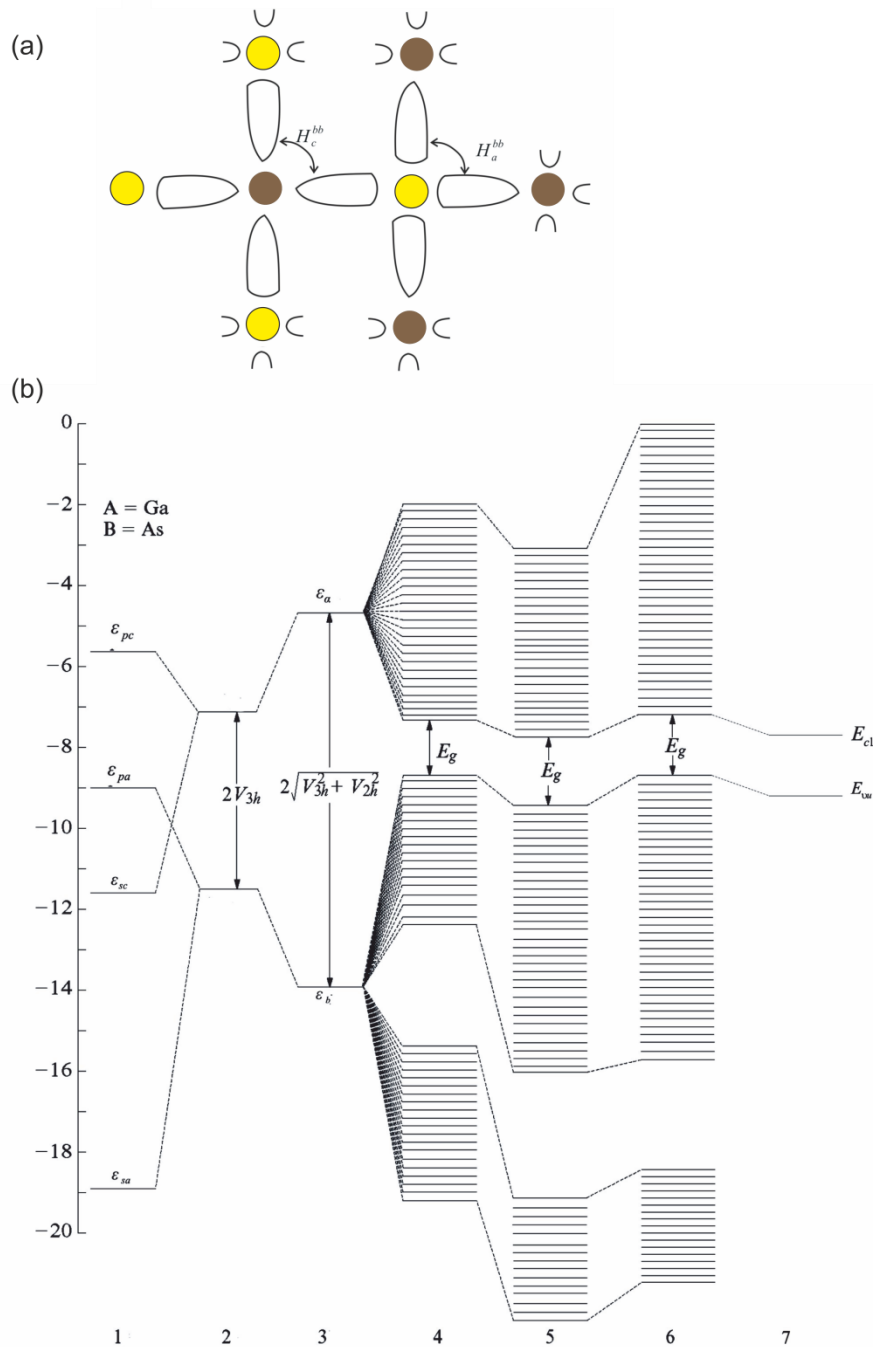


Fig. 12.10 **a** Schematic 2-D representation of the tetrahedral 3-D actual structure of a compound III-V semiconductor such as GaAs and the (asymmetric) molecular bonding orbitals. **b** The atomic p and s energy levels of each atom in eV (starting step 1); the sp^3 hybrid level of each atom (step 2); the bonding and antibonding molecular levels (step 3); the resulting valence and conduction bands around the bonding and the antibonding molecular levels respectively (step 4). Notice that the valence band is split to two subbands as a result of H_a^{bb} and H_c^{bb} being different (in analogy with the case of Fig. 12.5c). The (5), (6), and (7) columns show how successively more sophisticated approximations modify the bands and the gap

7. In a liquid the longitudinal speed of sound can be estimated by the formula :

$$(\bar{r} \equiv r/a_B)$$

$$(a) \nu \approx \frac{e^2}{\hbar} \quad (b) \nu \approx \frac{\hbar}{m_e a_B \bar{r}} \quad (c) \nu \approx \frac{\hbar}{m_p a_B \bar{r}} \quad (d) \nu \approx \frac{\hbar}{\sqrt{m_e m_a} a_B \bar{r}}$$

8. In a liquid the longitudinal speed of sound is given by the formula:

$$(a) \nu = B / \rho \quad (b) \nu = (B / \rho)^2 \quad (c) \nu = (B / \rho)^{1/2} \quad (d) \nu = (B / \rho)^{1/3}$$

9. In a solid a kind of average between the longitudinal and the transverse velocity of sound given by the formula $\nu = (B / \rho)^{1/2}$ can be estimated as follows:

$$(a) \nu \approx 80 / (\bar{r}^2 \sqrt{A_B}) \text{ km/s} \quad (b) \nu \approx 80 / (\bar{r}^2 A_B) \text{ km/s}$$

$$(c) \nu \approx 80 / (\bar{r} \sqrt{A_B}) \text{ km/s} \quad (d) \nu \approx 80 / (\bar{r} A_B) \text{ km/s}$$

10. The Debye temperature Θ_D , which is involved in the thermodynamic quantities due to lattice vibrations, can be estimated as follows:

$$(a) \Theta_D \approx \frac{7390}{\bar{r}^3 \sqrt{A_B}} \text{ K} \quad (b) \Theta_D \approx \frac{21000}{\bar{r}^2 \sqrt{A_B}} \text{ K}$$

$$(c) \Theta_D \approx \frac{7390}{\bar{r}^2 A_B} \text{ K} \quad (d) \Theta_D \approx \frac{21000}{\bar{r}^2 A_B} \text{ K}$$

11. The unit of resistivity in the atomic system of units is:

$$(a) = \hbar / e^2 \quad (b) = \alpha \hbar / e^2 \quad (c) = \hbar a_B / e^2 \quad (d) = \hbar a_B \alpha / e^2$$

12. The unit of resistivity in the atomic system of units has the following value:

$$(a) 4108 \Omega \quad (b) 188.4 \Omega \quad (c) 0.1586 \mu\Omega \cdot \text{cm} \quad (d) 21.74 \mu\Omega \cdot \text{cm}$$

13. The resistivity ρ of crystalline metals is due to the existence of deviations from the perfect periodicity such as defects, foreign atoms and, mainly, thermal oscillations of the ions. The resistivity is given by the approximate formula:

$$(a) \rho = 3c_1 (\hbar a_B / e^2) (T / T_0) \approx c_1 (0.0002T) \mu\Omega \cdot \text{cm}$$

$$(b) \rho = 3c_1 (\hbar a_B / e^2) \bar{r}^3 (T / T_0) \approx c_1 (0.006T) \mu\Omega \cdot \text{cm}$$

$$(c) \rho = 3c_1 (\hbar a_B / e^2) \approx c_1 65 \mu\Omega \cdot \text{cm}$$

$$(d) \rho = 3c_1 (\hbar a_B / e^2) (T / T_0)^2 \approx c_1 6,5 \times 10^{-10} T^2 \mu\Omega \cdot \text{cm}$$

14. The resistivity ρ depends on the concentration of carriers, $n_{e,h}$, (electrons or holes) on their electric charge, $\mp e$, and, finally, on the scatterings which macroscopically appear as a friction force proportional to the average velocity; the proportionality constant for dimensional reasons has the form $m_{e,h}^* / \tau_{e,h}$, where $m_{e,h}^*$ is the effective mass and $\tau_{e,h}$ is the so-called relaxation time for electrons or holes respectively. Dimensional analysis suggests that the formula for the conductivity has the following form in the G-CGS system.

$$(a) \sigma_{e,h} = \frac{e n_{e,h}}{m_{e,h}^* / \tau_{e,h}} \quad (b) \sigma_{e,h} = \frac{e^2 n_{e,h}}{m_{e,h}^* / \tau_{e,h}}$$

$$(c) \sigma_{e,h} = \frac{n_{e,h}}{e m_{e,h}^* / \tau_{e,h}} \quad (d) \sigma_{e,h} = \frac{1}{e n_{e,h} m_{e,h}^* / \tau_{e,h}}$$

15. Dimensional analysis leads to the following formula for the conductivity of metals in terms of the mean free path $\ell = v_F \tau$ and in the G-CGS system:

$$(a) \sigma = \frac{m_e v_F}{e^2 n \ell} \quad (b) \sigma = \frac{p_F \ell}{e^2 n} \quad (c) \sigma = \frac{e^2 p_F \ell}{n} \quad (d) \sigma = \frac{e^2 n \ell}{p_F}$$

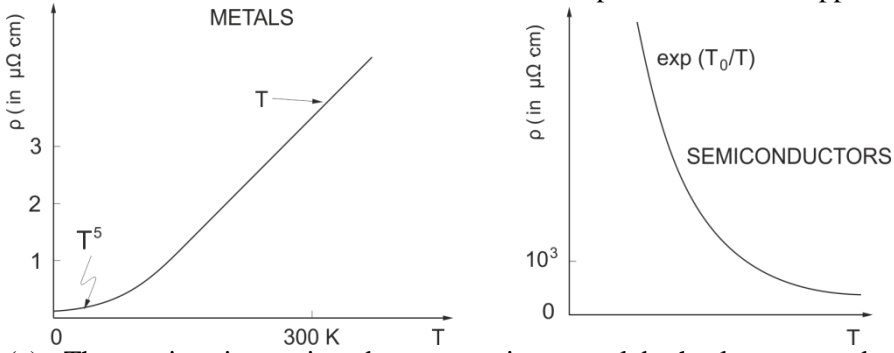
16. From the formula for the metallic conductivity and the dimensional result for the size of the conductivity (using the replacement $a_B \rightarrow \bar{r} a_B$), the magnitude of the electronic mean free ℓ path is estimated as:

(a) $\ell = 1 \text{ cm}$ (b) $\ell = 0.1 \text{ mm}$ (c) $\ell = 1 \text{ }\mu\text{m}$ (d) 1 nm

17. From the formula $\sigma_{e,h} = e^2 n_{e,h} / (m_{e,h}^* / \tau_{e,h})$ for the electric conductivity of electrons or holes we deduce that the general expression for the conductivity of a semiconductor is the following (Usually we define the mobility $\mu_{e,h}$ by the relation $|\mu_{e,h}| \equiv |e| \tau_{e,h} / m_{e,h}^*$):

(a) $\sigma = (e^2 n_e \tau_e / m_e^*) + (e^2 n_h \tau_h / m_h^*)$
 (b) $\rho = \rho_e + \rho_h = (e^2 n_e \tau_e / m_e^*)^{-1} + (e^2 n_h \tau_h / m_h^*)^{-1}$
 (c) $\sigma^{-2} = (e^2 n_e \tau_e / m_e^*)^{-2} + (e^2 n_h \tau_h / m_h^*)^{-2}$
 (d) $\sigma^2 = (e^2 n_e \tau_e / m_e^*)^2 + (e^2 n_h \tau_h / m_h^*)^2$

18. The graphs below present the typical temperature dependence of the resistivity, ρ , of metals and semiconductors. What is the correct explanation for this opposite behavior?



- (a) The carriers in semiconductors are in general both electrons and holes. Thus the electric current due to electrons partially cancels that due to holes; this cancellation tends to become complete as the temperature tends to the absolute zero.
- (b) From the relation $\rho_\eta = m_e / (e^2 n \tau)$ we conclude that the relaxation time τ is the only one which depends on the temperature. Thus τ must be a decreasing function of temperature for metals and an increasing one for semiconductors.
- (c) In the formula $\rho_\eta = m_e / (e^2 n \tau)$ the concentration n is an exponentially increasing function of temperature for semiconductors and a decreasing function in metals.
- (d) For both metals and semiconductors τ is decreasing as the temperature is raised. The concentration of carriers n in metals does not depend on the temperature, while is increasing exponentially for semiconductors as the temperature is raised.
19. In the jellium model the cohesive energy U of a metal is given by:
- (a) $U / N(\hbar^2 / m_e a_B^2) = (a / \bar{r}^{12}) - (\gamma / \bar{r}^6)$
 (b) $U / N(\hbar^2 / m_e a_B^2) = (a / \bar{r}^6) - (\gamma / \bar{r}^4)$, $\bar{r} \equiv r / a_B$
 (c) $U / N(\hbar^2 / m_e a_B^2) = (a / \bar{r}^2) - (\gamma / \bar{r}^4)$
 (d) $U / N(\hbar^2 / m_e a_B^2) = (a / \bar{r}^4) - (\gamma / \bar{r}^2)$
20. In the jellium model the bulk modulus B of a metal is given by the formula (in Mbar):
- (a) $B = 15.6 a / \bar{r}^2$ (b) $B = 15.6 a / \bar{r}^3$

$$(c) B = 15.6a / \bar{r}^4$$

$$(d) B = 15.6a / \bar{r}^5, \bar{r} \equiv r / a_B$$

21. According to the jellium model the parameters a and γ for Al are equal to 13.6 and 9.03 respectively. The resulting value of \bar{r} is:

$$(a) \bar{r} = 3.01 \quad (b) \bar{r} = 1.51 \quad (c) \bar{r} = 6.02 \quad (d) \bar{r} = 9.03$$

22. According to the jellium model the parameters a and γ for Al are equal to 13.6 and 9.03 respectively. The resulting value for the bulk modulus B is in Mbar :

$$(a) 13.6 \quad (b) 15.6 \quad (c) 9.03 \quad (d) 0.86$$

23. For a compound semiconductor we define the polarity index by $a_p \equiv V_{3h} / \sqrt{V_{2h}^2 + V_{3h}^2}$ and the metallicity index by $a_m \equiv 2\bar{V}_1 / \sqrt{V_{2h}^2 + V_{3h}^2}$, where $\bar{V}_1 = (\varepsilon_{pc} - \varepsilon_{sc} + \varepsilon_{pa} - \varepsilon_{sa}) / 8$. The approximate formula for the size of the gap E_g is:

$$(a) E_g = 2\sqrt{V_{2h}^2 + V_{3h}^2} - \bar{V}_1 \quad (b) E_g = 2\sqrt{V_{2h}^2 + V_{3h}^2} - 2\bar{V}_1$$

$$(c) E_g = 2\sqrt{V_{2h}^2 + V_{3h}^2} - 3\bar{V}_1 \quad (d) E_g = 2\sqrt{V_{2h}^2 + V_{3h}^2} - 4\bar{V}_1$$

24. For the compound III/V semiconductor GaAs, the relevant atomic levels are (in eV) - 5.67, and -11.55 for Ga and -8.98 and -18.91 for As. Find the hybrids atomic levels, the bonding and antibonding molecular levels, and the energy bands. The bond length in GaAs is 2.448 Å. Estimate the magnitude of the gap E_g (in eV) in GaAs;

$$(a) 0.7 \quad (b) 1,1 \quad (c) 1.4 \quad (d) 2.9$$

25. Estimate the size of the gap E_g (in eV) in Si, given the following data: $\varepsilon_s = -14.79\text{eV}$, $\varepsilon_p = -7.58\text{eV}$ and $d = 2.3517\text{Å}$

$$(a) 0.5 \quad (b) 1.66 \quad (c) 2.7 \quad (d) 4.1$$

26. For a 1-D LCAO model with one relevant atomic orbital per unit cell (of length d), the diagonal matrix element is ε_0 and the one between nearest neighbors is V_2 . The dispersion relation between the eigenenergy ε and the wavenumber k is:

$$(a) \varepsilon = \varepsilon_0 + V_2 d^2 k^2 \quad (b) \varepsilon = \varepsilon_0 - V_2 d^2 k^2$$

$$(c) \varepsilon = \varepsilon_0 + 2V_2 \cos(kd) \quad (d) \varepsilon = \varepsilon_0 + V_2 dk$$

27. For a 1-D LCAO model with one relevant atomic orbital 1s per unit cell (of length d), the diagonal matrix element is ε_0 and the one between nearest neighbors is V_2 . The effective mass in the limit $k \rightarrow 0$ is given by:

$$(a) m^* = -\hbar^2 / 2V_2 d^2 \quad (b) m^* = -\hbar^2 / V_2 d^2$$

$$(c) m^* = \hbar^2 / 2V_2 d^2 \quad (d) m^* = \hbar^2 / V_2 d^2$$

28. The definition of the effective mass for a particle moving in a 3-D periodic potential such that its eigenenergy $\varepsilon_n(\mathbf{k})$ is a function of the wavevector \mathbf{k} and the band index n , is as follows:

$$(a) 1/m_{i,n}^* \equiv \hbar^{-1} \nabla_{\mathbf{k}} \varepsilon_n(\mathbf{k}) \quad (b) 1/m_{i,n}^* \equiv \hbar^{-2} \Delta_{\mathbf{k}} \varepsilon_n(\mathbf{k})$$

$$(c) 1/m_{i,n}^* \equiv \hbar^{-2} \nabla_{\mathbf{k}} \times (\nabla_{\mathbf{k}} \varepsilon_n(\mathbf{k})) \quad (d) 1/m_i^* \equiv \hbar^{-2} \partial^2 \varepsilon_n(\mathbf{k}) / (\partial k_i)^2$$

29. For a particle of effective mass m^* moving in a 3D volume V its energy is given by $\varepsilon(\mathbf{k}) = E_a + \hbar^2 k^2 / 2m^*$. The density of states $\rho(E)$ is given by the following relation:

$$(a) \rho(E) \approx \left[V |m^*|^{3/2} / \sqrt{2\pi^2 \hbar^3} \right] (E - E_a)$$

$$(b) \quad \rho(E) \approx \left[V |m^*|^{3/2} / \sqrt{2\pi^2 \hbar^3} \right] |E - E_a|$$

$$(c) \quad \rho(E) \approx \left[V |m^*|^{3/2} / \sqrt{2\pi^2 \hbar^3} \right] |E - E_a|^{3/2}$$

$$(d) \quad \rho(E) \approx \left[V |m^*|^{3/2} / \sqrt{2\pi^2 \hbar^3} \right] |E - E_a|^{1/2}$$

30. The dielectric constant of Si is 12.1 and the average effective mass in the CB is $m_e^* = 0.329m_e$. Replacing a Si atom by a P atom will produce an impurity level at ε_i in the gap. If E_g is the lower edge of the CB, the difference $E_g - \varepsilon_i$ is:

$$(a) 1\text{eV} \quad (b) 0.362\text{eV} \quad (c) 0.091\text{eV} \quad (d) 0.030\text{eV}$$

31. The dielectric constant of GaAs is 12.85 and the average effective mass in its VB is $m_e^* = 0.51m_e$. Replacing an As atom by a Ge atom will produce a bound state of “radius” a_B^* which is approximately equal to:

$$(a) 0.529 \text{ \AA} \quad (b) 6.8 \text{ \AA} \quad (c) 13.3 \text{ \AA} \quad (d) 171 \text{ \AA}$$

32. The electronic concentration $n \equiv N_{e,ZA}/V$ in the CB of a semiconductor is given by the relation $n = (2/V) \int_{E_g}^{\infty} \rho_{ZA}(E) f(E) dE$. Taking into account that the DOS is $\rho_{ZA}(E) \approx (A_c / \pi^{1/2})(E - E_g)^{1/2}$ and approximating the Fermi distribution by the Boltzmann one we find that:

$$(a) \quad n \approx A_c (k_B T)^{3/2} \exp[-(E_g / k_B T)]$$

$$(b) \quad n \approx A_c (k_B T)^{3/2} \exp[-(\mu / k_B T)]$$

$$(c) \quad n \approx A_c (k_B T)^{3/2} \exp[(E_g / k_B T)]$$

$$(d) \quad n \approx A_c (k_B T)^{3/2} \exp[-(E_g - \mu) / k_B T]$$

33. The concentration of holes $p \equiv N_{h,VB}/V$ in the VB of a semiconductor is given by the relation $p = (2/V) \int_{-\infty}^0 \rho_{VB}(E) [1 - f(E)] dE$. Taking into account that the DOS is $\rho_{VB}(E) \approx (A_h / \pi^{1/2})(-E)^{1/2}$ and approximating the Fermi distribution by the Boltzmann one we find that:

$$(a) \quad p \approx A_h (k_B T)^{3/2} \exp[-(\mu / k_B T)]$$

$$(b) \quad p \approx A_h (k_B T)^{3/2} \exp[(E_g - \mu) / k_B T]$$

$$(c) \quad p \approx A_h (k_B T)^{3/2} \exp[(\mu / k_B T)]$$

$$(d) \quad p \approx A_h (k_B T)^{3/2} \exp[-(E_g - \mu) / k_B T]$$

34. The dielectric constant ε of Si is 12.1 and the average effective mass m_e^* in the CB is $m_e^* = 0.329m_e$. Replacing a Si atom by a P atom will produce an impurity level at ε_i in the gap. If E_g is the lower edge of the CB, the difference $E_1 = E_g - \varepsilon_i$ is:

$$(a) E_1 = e^2 / 2a_B, \quad (b) E_1 = e^2 m_e^* / 2a_B m_e \varepsilon^2$$

$$(c) E_1 = e^2 \varepsilon m_e^* / 2a_B m_e, \quad (d) E_1 = e^2 \varepsilon^2 / 2a_B$$

35. In a semiconductor with N_a concentration of acceptors and N_d ($N_a > N_d$) concentration of donors, which is the relation connecting the electronic concentrations n, n_d in the CB and in donors respectively with the hole concentrations p, p_a in the VB

and in acceptors respectively? (Hint: Consider first the case for $T = 0\text{K}$ before you give the answer for $T \neq 0\text{K}$)

(a) $n + n_d = p + p_a$, (b) $n + n_d = p + p_a + N_a + N_d$,

(c) $n + n_d = p + p_a - N_a + N_d$ (d) $n + n_d = p + p_a + N_a - N_d$

36. In a semiconductor the concentrations of electrons n and holes p in the CB and in the VB respectively are given by the formulae:

$$n \approx A_c (k_B T)^{3/2} \exp[-(E_g - \mu) / k_B T], \quad p \approx A_h (k_B T)^{3/2} \exp[-(-\mu) / k_B T],$$

$A_i \propto m_i^*$, $i = c, h$. Then in the absence of donors and acceptors (intrinsic case) the chemical potential is:

(a) $\mu = (E_g / 2) - (3k_B T / 4) \ln(m_h^* / m_c^*)$,

(b) $\mu = (E_g / 2) - (3k_B T / 4) \ln(m_c^* / m_h^*)$

(c) $\mu = E_g - (3k_B T / 4) \ln(m_h^* / m_c^*)$

(d) $\mu = E_g + (3k_B T / 4) \ln(m_h^* / m_c^*)$

37. In a semiconductor the concentrations of electrons n and holes p in the CB and in the VB respectively are given by the formulae: $n \approx A_c (k_B T)^{3/2} \exp[-(E_g - \mu) / k_B T]$,

$$p \approx A_h (k_B T)^{3/2} \exp[-(-\mu) / k_B T], \quad A_i \propto m_i^*, \quad i = c, h.$$

Then in the absence of donors and acceptors (intrinsic case) the concentration of holes in the VB is:

(a) $p \approx (A_e A_h)^{1/2} (k_B T)^{3/2} \exp(-E_g / k_B T)$

(b) $p \approx (A_e A_h)^{1/2} (k_B T)^{1/2} \exp(-E_g / k_B T)$

(c) $p \approx (A_e A_h)^{1/2} (k_B T)^{3/2} \exp(-E_g / 2k_B T)$

(d) $p \approx (A_e A_h)^{1/2} (k_B T)^{1/2} \exp(-E_g / 2k_B T)$

38. In a semiconductor of N_a and N_d concentrations of acceptors and donors respectively ($N_d - N_a \equiv \delta N \gg n_i$, where n_i is the electron concentration in the CB in the intrinsic case), the concentration of electrons n in the CB is the following: (Take into account that $n + n_d = p + p_a - N_a + N_d$)

(a) $n \approx \frac{1}{2} (\sqrt{\delta N^2 + 4n_e^2} - \delta N)$,

(b) $n \approx \frac{1}{2} (\sqrt{\delta N^2 + 4n_e^2} + \delta N)$,

(c) $n \approx \delta N$,

(d) $n \approx n_i$

39. In a pure crystalline Si one atom per million has been replaced by a P atom. As a result of this replacement the conductivity will increase by a factor x , where:

(a) $x = 1.000001$, (b) $x = 5.3 \times 10^6$, (c) $x = 15.4$, (d) $x = 2$

40. In a copper wire the current density is equal to 16A/mm^2 . For copper the valence $\zeta = 1$ and $\bar{r} = 2.67$. The average velocity (in m/s) of electrons along the direction of the applied electric field is:

(a) 1.18×10^{-3} , (b) 1.18 (c) 1.18×10^3 (d) 1.18×10^6

12.12 Solved problems

1. For water determine the radius per molecule \bar{r} , the velocity of sound, and the bulk modulus.

Solution: From the relations $\rho_M = 2.675(A_w / \bar{r}^3) \text{g} / \text{cm}^3 = 1 \text{gr}$ and $A_w = 18$ it is obtained that $\bar{r} = 3.64$. The velocity of sound for dimensional reasons is given by the following formula $\nu = \eta (\hbar / m_e a_B \bar{r}) \times \sqrt{m_e / (u A_B)}$. The numerical factor η (in the present case of hydrogen bonding of the molecules) is not around 1.6 as in the presence of strong bonds; it is expected to be about 3.5 smaller. Taking into account that $(\hbar / m_e a_B) = c / 137$, $(m_e / u) = 1 / 1823$ we find $\nu = 1.52 \text{ km/s}$. From the relation $\nu = \sqrt{B / \rho_M}$ we obtain $B = 2.29 \times 10^9 \text{ N/m}^2 = 22900 \text{ bar}$

2. Estimate the coefficient of surface tension for a liquid (e.g. water)

Solution: The surface tension is due to the difference appearing in the cohesive energy per atom (or molecule, if we are considering water) depending on whether the atom is in the bulk or at the surface. In the first case the cohesive energy is equal to $\frac{1}{2} A_{m,b} \epsilon$, where $A_{m,b} \approx 8$ is the number of nearest neighbors and ϵ is the interaction energy per pair of atoms (or molecules), while in the second case is equal to $\frac{1}{2} A_{m,s} \epsilon$, where $A_{m,s} \approx 5$ is the number of nearest neighbors for an atom (or molecule) located at the surface. The surface tension coefficient σ is the difference $\frac{1}{2} A_{m,b} \epsilon - \frac{1}{2} A_{m,s} \epsilon$ divided by the surface area s per atom (or molecule). For water, where the molecules are held together by the weak hydrogen bond, the quantity $\frac{1}{2} A_{m,b} \epsilon$ is about 0.3 eV so that $\epsilon \approx 0.075 \text{ eV}$; the area s is expected to be about twice the quantity $\pi a_B^2 \bar{r}^2 = \pi (0.529 \times 3.64)^2 \times 10^{-20} \text{ m}^2 = 11.6 \times 10^{-20} \text{ m}^2$. Thus $\sigma = \frac{3}{8} (0.3 / 23.2) \times 10^{20} \text{ eV/m}^2 = 0.075 \text{ J/m}^2$ vs. 0.073 J/m^2 for the experimental value at $T = 20^\circ \text{C}$. For mercury $\bar{r} = 3.36$ and $\frac{1}{2} A_{m,b} \epsilon$ can be estimated at about 1 eV; the resulting value for σ is about 0.3 J/m^2 vs. 0.486 J/m^2 for the experimental value at $T = 20^\circ \text{C}$. The discrepancy may be due to the factor of 2 we included in the surface area per atom which is probably too big for mercury.

12.13 Unsolved problems

1. Does sound propagate faster in aluminum or in lead? Justify your answer.
2. In n-type Si ($N_d = 5 \times 10^{16} \text{ cm}^{-3}$) the current density is 0.1 A/cm^2 at $T = 300 \text{ K}$. What is the average velocity of the electrons producing this current density?