Benha University
Faculty of Science
Phys. Department

Solid State 1
PHY 353
Time: 3 Hours

Answer all questions

Part A
Choice the correct answer **Multiple Choice [10 Marks].**

1. The local field E_{Loc} =
   Ⓐ $E+\frac{P}{3\varepsilon_o}$ Ⓑ $P+\frac{E}{3\varepsilon_o}$ Ⓒ $P-\frac{E}{3\varepsilon_o}$ Ⓓ $E-\frac{P}{3\varepsilon_o}$
2. In classical theory, kinetic energy of free electron gas is
   Ⓐ $\frac{1}{2}k_BT$ Ⓑ k_BT Ⓒ $\frac{3}{2}k_BT$ Ⓓ $\frac{5}{2}k_BT$
3. The good insulators should have
   Ⓐ High resistivity
   Ⓑ High dielectric strength
   Ⓒ High permitivity
   Ⓓ All the above
4. Drude and Lorentz proposed
   Ⓐ Classical theory Ⓑ Both Ⓒ Quantum theory Ⓓ None
5. According to classical theory, metal is an aggregate of
   Ⓐ Atoms and molecules
   Ⓑ Nuclei and electrons
   Ⓒ positive ions and electron gas
   Ⓓ positive ions and negative ions
6. The Clausius amd Mosotti relation is
   Ⓐ $\frac{\varepsilon_r-1}{\varepsilon_r-2}=\frac{N\alpha}{3\varepsilon_o}$ Ⓑ $\frac{\varepsilon_r+1}{\varepsilon_r-2}=\frac{N\alpha}{3\varepsilon_o}$ Ⓒ $\frac{\varepsilon_r+1}{\varepsilon_r+2}=\frac{N\alpha}{3\varepsilon_o}$ Ⓓ $\frac{\varepsilon_r-1}{\varepsilon_r+2}=\frac{N\alpha}{3\varepsilon_o}$
7. The Ohm's law states,
   Ⓐ $J = \sigma E$ Ⓑ $J = \sigma/E$ Ⓒ $\sigma = JE$ Ⓓ None
8. The effective mass of the electron varies with
   Ⓐ position Ⓑ Velocity Ⓒ Potential Ⓓ Energy
9. The group of velocity of the electrons is
   Ⓐ $V_g=\frac{d^2\omega}{dK^2}$ Ⓑ $V_g=\frac{d^2K}{d\omega^2}$ Ⓒ $V_g=\frac{dK}{d\omega}$ Ⓓ $V_g=\frac{d\omega}{dK}$
10. The resistivity of a metal is
   Ⓐ $\rho=\frac{m}{ne\tau}$ Ⓑ $\rho=\frac{m}{ne^2\tau}$ Ⓒ $\rho=\frac{ne\tau}{m}$ Ⓓ $\rho=\frac{ne^2\tau}{m}$

Problem

11. Calculate the mean free path of electron in copper of density 8.5×10^{28} m^{-3} and a resistivity 1.69×10^{-8} Ω - m. [given that the $m_e = 9.11\times10^{-34}$ Kg, T = 300 K and $e = 1.69\times10^{-19}$ Coul]. [10 Marks]
12. According the free electron theory, describe density of states in an atom. [10 Marks]
13. Derive an expression for ionic polarizability α_I. [10 Marks]

Answer all questions
Answer Section

MULTIPLE CHOICE

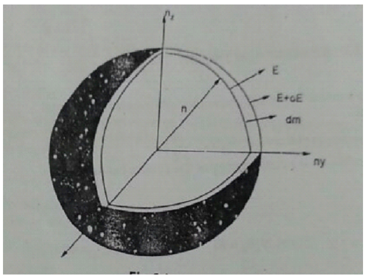
1. ANS: A
2. ANS: C
3. ANS: D
4. ANS: A
5. ANS: C
6. ANS: D
7. ANS: A
8. ANS: B
9. ANS: A
10. ANS: B

PROBLEM

11. ANS:

$$\rho = \frac{\sqrt{3k_B mT}}{ne^2\lambda} \qquad \triangleright\ \lambda = \frac{\sqrt{3k_B mT}}{ne^2\rho} = \frac{\sqrt{3x1.38x10^{-23}JK^{-1}x300K}}{8.5x10^{28}m^{-3}x(1.6x10^{-16})^2x1.69x10^{-8}\Omega - m} = 2.88m$$

12. ANS:
<u>Density of states</u>



$No.E.States\ in\ Sphere\ of\ radius\,n = \frac{1}{8}\left(\frac{4}{3}\pi n^3\right) \quad \rightarrow \ (1)$

$No.E.States\ in\ Sphere\ of\ radius\,(n+dn) = \frac{1}{8}\left(\frac{4}{3}\pi (n+dn)^3\right) \quad \rightarrow \ (2)$

$$g'(E)dE = \frac{1}{8}\left(\frac{4}{4}\pi(n+dn)^3\right) - \frac{1}{8}\left(\frac{4}{3}\pi n^3\right) = \frac{\pi}{6}[(n+dn)^3 - n^3]$$
$$= \frac{\pi}{6}\,[n^3 + dn^3 + 3n^2dn + 3ndn^2 - n^3]$$

Neglecting the higher order terms

$$g'(E)dE = \frac{\pi}{6}[3n^2dn] = \frac{\pi}{2}[n(ndn)] \quad \longrightarrow (3)$$

n^{th} energy level

$$E = \frac{n^2h^2}{8ma^2}$$

$$n = \left(\frac{8ma^2}{h^2}E\right)^{\frac{1}{2}} \quad \longrightarrow (4)$$

Differentiating eq. 4 and multiply both side in n

$$ndn = \left(\frac{8ma^2}{h^2}E\right)^{\frac{1}{2}} . \left(\frac{8ma^2}{h^2}\right)^{\frac{1}{2}} \frac{1}{2} E^{\frac{1}{2}-1} dE = \frac{1}{2}\left(\frac{8ma^2}{h^2}\right) dE \quad \longrightarrow (5)$$

Substitute eqs. 4 and 5 in eq. 3

$$g'(E)dE = \frac{\pi}{2}\left[\left(\frac{8ma^2}{h^2}E\right)^{\frac{1}{2}} . \frac{1}{2}\left(\frac{8ma^2}{h^2}\right) dE\right] = \frac{\pi}{4}\left(\frac{8ma^2}{h^2}E\right)^{\frac{3}{2}} E^{\frac{1}{2}} dE \quad \longrightarrow (6)$$

Pauli's exclusion principle

$$g'(E)dE = 2 \times \frac{\pi}{4}\left(\frac{8ma^2}{h^2}E\right)^{\frac{3}{2}} E^{\frac{1}{2}} dE = \frac{\pi}{2}\left(\frac{8m}{h^2}E\right)^{\frac{3}{2}} a^3 E^{\frac{1}{2}} dE \quad \longrightarrow (7)$$

DOS, $g\ (E)dE = \frac{g'(E)dE}{V} = \frac{\pi}{2}\left(\frac{8m}{h^2}E\right)^{\frac{3}{2}} E^{\frac{1}{2}}dE \qquad \rightarrow (8)$

Where $V = a^3$

13. ANS:
Hence, the net distance between two ions is $X = X_1 + X_2$ 7.32

Lorentz force acting on the positive ion = +e E

………………………………0n the negative ion = - eE 7.33

When ions are displace in their respective directions from the mean positions, and then a restoring force appears on the ions, which tend to move the ions back to mean positions.

The storing force acting on the positive ion = $-K_1 X_1$

……………………………………on the negative ion = $+K_2 X_2$ 7.34

At equilibrium the Lorentz force and restoring force will be equal and opposite, hence from eqs. 7.33 and 7.34,

$E\,E = K_1 X_1$ and $e\,E = K_2 X_2$

Where K_1 and k_2 are restoring forces constants

$X_1 = e\,E/K_1$ and $X_2 = e\,E/K_2$

Where $K_1 = M\,\omega_o^2$ and $K_2 = m\,\omega_o^2$. ωo is the angular velocity of the ions. Hence,

$$X_1 = \frac{e\,E}{M\omega_o^2} \quad and \quad X_2 = \frac{e\,E}{m\omega_o^2} \qquad 7.35$$

Substituting eq. 7.35 in eq. 7.32

$$X_1 = \frac{e\,E}{M\omega_o^2} + \frac{e\,E}{m\omega_o^2} = \frac{e\,E}{\omega_o^2}\left(\frac{1}{M} + \frac{1}{m}\right) \qquad 7.36$$

The dipole moment is equal to the product of charge and separation between them. Therefore, from equation 7.36, the dipole moment is

$$\mu_I = e \cdot \frac{e\,E}{\omega_o^2}\left(\frac{1}{M} + \frac{1}{m}\right) = \frac{e^2\,E}{\omega_o^2}\left(\frac{1}{M} + \frac{1}{m}\right) = \frac{e^2}{\omega_o^2}\left(\frac{1}{M} + \frac{1}{m}\right) E \qquad 7.37$$

But the dipole moment, $\mu_{ind} = \alpha_I E$ 7.38

On comparing eqs. 7.37 and 7.38

$$\alpha_I = \frac{e^2}{\omega_o^2}\left(\frac{1}{M} + \frac{1}{m}\right) \qquad 7.39$$