

Solutions to Problems in Solid State Physics II

Problem 2005-I

ε_A is the maximum energy of band 1 (follows from the specification of the Fermi surface). The number of electronic states in one band, within the 1. Brillouin zone, is twice the number of k states, i.e. twice the number of unit cells in the system. If $\varepsilon_h < \varepsilon_c$ all states in band 1, and no states in band 2, would be occupied by electrons at zero temperature, implying that

1) the system would be an insulator (or semiconductor).

The reciprocal lattice of an fcc is a bcc lattice. In the bcc reciprocal lattice there are 8 equivalent (111) reciprocal lattice points lying at the corners of the 1. Brillouin zone, each counting one-eighth. This implies that there is, effectively, one hole and one electron Fermi surface in one Brillouin zone. With the use of the notation introduced on the figure, we have:

$$\varepsilon_F = \varepsilon_c + \frac{(\hbar k_c)^2}{2m_c} = \varepsilon_h - \Delta + \frac{(\hbar k_h)^2}{2m_h}, \quad \varepsilon_F = \varepsilon_h - \frac{(\hbar k_h)^2}{2m_h}. \quad (1)$$

The number of holes (i.e. the number of missing electrons) in band 1 is equal to the number of electrons occupying band 2, i.e.

$$n = p. \quad (2)$$

and since both bands are parabolic, we may use Marder eq. (6.29) to obtain the lengths of the two Fermi wave vectors:

$$k_c = (3\pi^2 n)^{1/3}, \quad \text{and equivalently} \quad k_h = (3\pi^2 p)^{1/3}. \quad (3)$$

These equations are straightforwardly solved, and we get

$$2) \quad \varepsilon_F = \varepsilon_h - \frac{m_c}{m_c + m_h} \Delta.$$

$$3) \quad n = p = \frac{1}{3\pi^2} \left(\frac{2\Delta}{\hbar^2} \frac{m_c m_h}{m_c + m_h} \right)^{3/2}.$$

According to Marder eqs. (6.77) and (6.23), the specific heat is

$$c_V = \frac{\pi^2}{3} k_B^2 T D(\varepsilon_F), \quad D(\varepsilon_F) = \frac{m}{\hbar^3 \pi^2} \sqrt{2m\varepsilon_F} = \frac{mk_F}{\hbar^2 \pi^2}, \quad (4)$$

in the case of a parabolic band, when $T \ll \varepsilon_F/k_B$. In the present case, we need to require $T \ll \Delta/k_B$, and adding the electron- and hole-like contributions,

$$D(\varepsilon_F) = \frac{m_c k_c}{\hbar^2 \pi^2} + \frac{m_h k_h}{\hbar^2 \pi^2} = \frac{m_c + m_h}{\hbar^2 \pi^2} \left(\frac{2\Delta}{\hbar^2} \frac{m_c m_h}{m_c + m_h} \right)^{1/2} \quad (5)$$

the result is

$$4) \quad \gamma = c_V/T = \frac{k_B^2}{3\hbar^2} \sqrt{2m_c m_h (m_c + m_h) \Delta}.$$

Problems In Solid State Physics With Solutions

Jacques Cazaux



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Table of Contents Problems In Solid State Physics With Solutions

1. Understanding the eBook Problems In Solid State Physics With Solutions
 - The Rise of Digital Reading Problems In Solid State Physics With Solutions
 - Advantages of eBooks Over Traditional Books
2. Identifying Problems In Solid State Physics With Solutions
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Problems In Solid State Physics With Solutions
 - User-Friendly Interface
4. Exploring eBook Recommendations from Problems In Solid State Physics With Solutions
 - Personalized Recommendations
 - Problems In Solid State Physics With Solutions User Reviews and Ratings
 - Problems In Solid State Physics With Solutions and Bestseller Lists
5. Accessing Problems In Solid State Physics With Solutions Free and Paid eBooks

- Problems In Solid State Physics With Solutions Public Domain eBooks
 - Problems In Solid State Physics With Solutions eBook Subscription Services
 - Problems In Solid State Physics With Solutions Budget-Friendly Options
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 - ePub, PDF, MOBI, and More
 - Problems In Solid State Physics With Solutions Compatibility with Devices
 - Problems In Solid State Physics With Solutions Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Problems In Solid State Physics With Solutions
 - Highlighting and Note-Taking Problems In Solid State Physics With Solutions
 - Interactive Elements Problems In Solid State Physics With Solutions
 8. Staying Engaged with Problems In Solid State Physics With Solutions
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Problems In Solid State Physics With Solutions
 9. Balancing eBooks and Physical Books Problems In Solid State Physics With Solutions
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Problems In Solid State Physics With Solutions
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Problems In Solid State Physics With Solutions
 - Setting Reading Goals Problems In Solid State Physics With Solutions
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Problems In Solid State Physics With Solutions
 - Fact-Checking eBook Content of Problems In Solid State Physics With Solutions
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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