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ENGINEERING PHYSICS

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Unit III : Application of Quantum Mechanics to Electrical transport in Solids

- ***Suggested Reading***

1. ***Fundamentals of Physics, Resnik and Halliday, Chapter 41***
2. ***Solid state Physics, S.O Pillai, Chapter 6***
3. ***Concepts of Modern Physics, Arthur Beiser, Chapter 9***
4. ***Learning material prepared by the department-Unit III***

- ***Reference Videos***

1. ***Physics Of Materials-IIT-Madras/lecture-26.html***

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Unit III : Application of Quantum Mechanics to Electrical transport in Solids

Class #28

Merits of Quantum free electron theory :

- ***Temperature dependence of resistivity***
- ***Heat capacity due to free electrons***
- ***Conductivity dependence on electron concentration***

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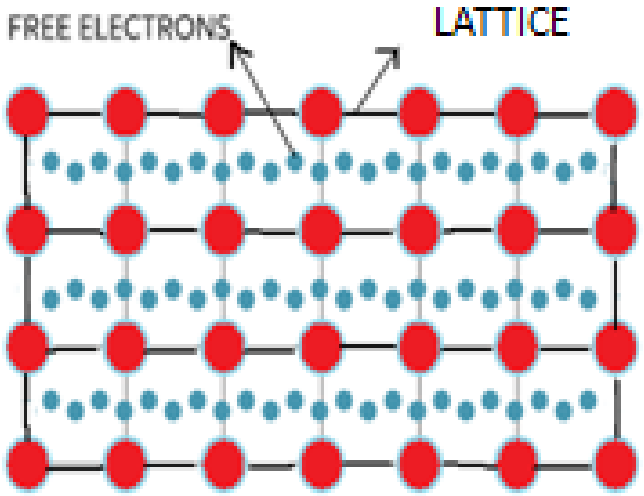
Temperature dependence of Resistivity



➢ *According to the CFET ionic centers are stationary and the resistivity originates from the scattering of the free electrons.*

➢ *The QFET takes into account of the thermal vibrations of the ionic array which accounts for the scattering of electrons.*

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Temperature dependence of Resistivity

- *The amplitude of the vibrations r of the lattice ions increase with increasing temperature.*
- *When ions vibrate the lattice presents an effective cross sectional area* $A = \pi r^2$ *for scattering.*
- *Effective cross sectional area A is proportional to temperature* $A \alpha T$
- *This will increase the probability of electron scattering at higher temperatures .*
- *Results in reduction of mean free path* λ *of the electrons* $\lambda \alpha 1/T$

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Temperature dependence of Resistivity

Expression for is conductivity $\sigma = \frac{ne^2\tau}{m} = \frac{ne^2\lambda}{mv_f}$

This implies that the conductivity is proportional to the mean free path

The electron mean free path λ *is inversely proportional to the scattering cross section.*

Hence the conductivity $\sigma \alpha 1/T$ *or resistivity* $\rho \alpha T$

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Heat capacity due to free electrons

Electronic specific heat is given by $C_{el} = \frac{dU}{dT}$

Then the total energy of electrons in one mole of the material is given by

*U = No of conduction electrons * Average energy*

At temperature T electrons can gain an energy $K_B T$*, but only electrons close to the Fermi level participate in the conduction.*

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Heat capacity due to free electrons

For a mole of electron gas, the fraction of electron that gain energy K_BT is given by $n_{eff} = \frac{N_a}{E_f} k_BT$

If the average thermal energy of the electrons is taken to be $\frac{3}{2} k_BT$

Then the total energy of electrons in one mole of the material is given by $U = n_{eff} \cdot \frac{3}{2} k_BT$

$$= \frac{3}{2} k_BT \frac{N_a}{E_f} . k_BT$$

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Heat capacity due to free electrons

$$= \frac{3}{2} . \frac{N_a}{E_f} . {k_B}^2 T^2$$

Electronic specific heat is given by $C_{el} = \frac{dU}{dT}$

$$= 3. \frac{N_a}{E_f} . {k_B}^2 T = 3R. \frac{k_B T}{E_f}$$

A more accurate evaluation of the electronic specific heat of mono valent metals results in the relation

$$C_{el} = \frac{\pi^2}{2} N \left(\frac{{k_B}^2 T}{E_f} \right)$$

This analysis gives the correct correlation with the experimental results.

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Conductivity variations with electron concentrations

According to QFET the conductivity expression is given by

$$\sigma = \frac{ne^2\tau}{m} \quad or \quad = \frac{ne^2\left(\frac{\lambda}{v_F}\right)}{m}$$

According to the above equation σ not only depends on the number of electrons per unit volume but also depends on the λ/v_F ratio.

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Class 28 . Quiz …

The concepts which are correct are….

1. *The quantum free electron theory takes accounts of the thermal vibrations of the ionic array, which accounts for the scattering of electrons.*
2. *The probability of electron scattering decreases with increasing temperature.*
3. *According to QFET resistivity of the metal is found to be inversely proportional to temperature.*
4. *For a given mole of electron gas, the fraction of electron that gain energy KT is* $n_{eff} = \frac{N_a}{E_f} kT$

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THANK YOU

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