

Effect of Ionization Energy in the Presence of Magnetic Field

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ABSTRACT: Metal-insulator transition in doped semiconductors is investigated in the presence of intense magnetic field. Using Thomas Fermi screening function and a screened coulomb potential in the Hamiltonian, a two parameter variational calculation leads to metallization. The correlation effect among the electrons is considered through an effective mass that depends on the spatial separation between impurities.

KEYWORDS: Semiconductors; Magnetic field effect; Metal - insulator transition

I.INTRODUCTION

Metal-insulator transitions are transitions from a metal (material with good electrical conductivity of electric charges) to an insulator (material where conductivity of charges is quickly suppressed). These transitions can be achieved by tuning various ambient parameters such as pressure or, in case of a semiconductor; doping. The classical band structure of solid state physics predicts the Fermi level to lie in a band gap for insulators and in the conduction band for metals, which means metallic behavior is seen for compounds with partially filled bands. However, some compounds have been found which show insulating behavior even for partially filled bands. This is due to the electron-electron correlation. Anderson localization is a general wave phenomenon that applies to the transport of electromagnetic waves, acoustic waves, quantum waves, spin waves, etc. This phenomenon is to be distinguished from weak localization, where the transition from metallic to insulating behavior is not due to disorder, but to a strong mutual Coulomb repulsion of electrons.[1-3]

MIT observed in doped semiconductors are referred as Mott transition. For a hydrogenic donor it has been observed that ionization energy increases with the strength of the magnetic field. Hence, it is interesting that, if MIT is possible in a magnetic field.

II.THEORY

Donor binding energy

The Hamiltonian for an isolated donor immersed in a dielectric constant ϵ_0 and an electron effective mass m^* is given by [4-6]

$$H_o = -\frac{\hbar^2 \nabla^2}{2m^*} - \frac{e^2}{\epsilon_0 r} e^{-\lambda r}$$

We have considered Thomas Fermi screening function with a screening parameter

$$\lambda = \left(\frac{4\pi e^2 \eta}{\epsilon_0} \right)^{\frac{1}{2}},$$

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$$\eta = \frac{3}{2} \left(\frac{N}{E_F} \right)$$

where is the density of states for electrons.

In the presence of magnetic field the above Hamiltonian becomes [7-9]

$$H_1 = \frac{1}{2m^*} \left(\vec{P} + \frac{e}{c} \vec{A} \right)^2 - \frac{e^2}{\epsilon_0 r} e^{-\lambda r}$$

Where A is the vector potential and c is the velocity of light. Define a Hamiltonian as

$$H_2 = \frac{1}{2m^*} \left(P + \frac{e}{c} A \right)^2 - \frac{e^2}{\epsilon_0 r}$$

And for convenience, we choose $l = (\hbar/2m^*c)^{1/2}$ as the unit of length and $E = \hbar\omega_c$ as the energy. Also define a dimensionless parameter for magnetic field, $\gamma = \hbar\omega/2R_y$ where R_y is the effective Rydberg. Call the system of units as Larsen unit (LU).

$$H_2 = - \left[\frac{\partial^2}{\partial \rho^2} + \frac{1}{\rho} \frac{\partial}{\partial \rho} + \frac{1}{\rho^2} \frac{\partial^2}{\partial \phi^2} + \frac{\partial^2}{\partial Z^2} \right] + \frac{L_z}{2} + \frac{\rho^2}{16} - \left(\frac{\gamma}{2} \right)^{-1/2} (\rho^2 + Z^2)^{-1/2}$$

In cylindrical co-ordinates. Chosen the magnetic field along Z direction. A trial wave function as

$$\psi = N e^{-\rho^2/8a^2} e^{-Z^2/8b^2}$$

With a and b as variational parameters.

III. MIT IN SEMICONDUCTORS

To study MIT, presence of all impurities situated in the neighborhood of a particular donor has to be considered. Assuming a Poisson like distribution of impurities, the leading term in the potential energy is of the form $V(r) = (e^2/\epsilon_0 r) e^{-\lambda r}$ within the Thomas-Fermi theory. So the Hamiltonian pertinent to this problem is H_1 . To find the ionization energies perturbation method is used.[10,11]

Treating the perturbation as

$$H' = H_1 - H_2 = - \frac{e^2}{\epsilon_0 r} (e^{-\lambda r} - 1)$$

And taking ψ as the zeroth order eigen function, the first order perturbation theory leads to

$$\Delta E^{(1)} = \frac{4(\gamma/2)^{-1/2}}{R} \left(\frac{1}{4} - \frac{1}{(2 + \lambda R)^2} \right)$$

where $R = \left((3/4)a^2b \right)^{1/3}$.

The ionization energy is given by

$$E_{ion}^{(1)} = E_{ion}^{(0)} + \Delta E^{(1)}.$$

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Table 1

The ionization energy and variational parameters for a donor in a magnetic field

γ	$E_{ion} (Ry^*)$
0.2	1.0314
0.5	1.2502
0.8	1.4242
1.0	1.5238
5.0	2.6150
10.0	3.3320
25.0	4.5700

IV.RESULTS AND DISCUSSION

Table 1 gives the variation of donor ionization energy of an isolated donor in a magnetic field. Since the ionization energy increases with magnetic field metallization is not possible within the isolated donor model.

V.CONCLUSION

The classical band structure of solid state physics predicts the Fermi level to lie in a band gap for insulators and in the conduction band for metals, which means metallic behavior is seen for compounds with partially filled bands. However, some compounds have been found which show insulating behavior even for partially filled bands. This is due to the electron-electron correlation. Anderson localization is a general wave phenomenon that applies to the transport of electromagnetic waves, acoustic waves, quantum waves, spin waves

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