THE CONDUCTANCE OF A QUANTUM WIRE

By

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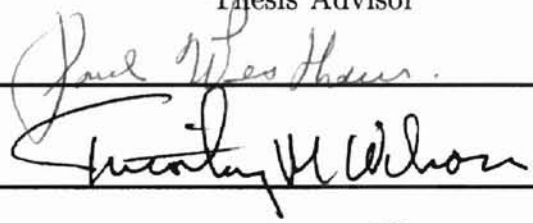

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

The Mesoscopic Physics usually deals with transport properties of the system whose dimensions are order of quantum phase coherence length scale l_ϕ. This is the length over which electrons diffuse before making a dephasing collision. In a dephasing collision, the phase of the electron wave function destructs. It is formally assumed that processes involving the emission or absorption of a phonon causes dephasing; on the other hand, collisions with static objects such as chemical impurities or the walls of sample do not effect or alter the phase of the wave function. Thus the phase coherence is disrupt when the state of the environment other than dominating random potentials is taken into account. For interacting disordered systems, the electron-electron interaction is known to dominate the phase coherence time τ_ϕ ($l_\phi \propto \sqrt{\tau_\phi}$) in comparison with the electron-phonon interaction at sufficiently low temperatures.

Collisions with impurities, phonons, or other electrons alters the momentum of the electron. The average distance traveled before changing the direction of current flow is the mean free path l. This length scale is order of μm or larger in high mobility samples. The modern lithography enables the fabrication of samples whose physical dimensions are on the order of their mean free path. Samples whose dimensions are smaller than l are in ballistic regime.

At low temperatures, electrons are in the ground state and the energy levels up the Fermi surface with energies $E < E_F$ are fully occupied where E_F is the Fermi energy. k_F is the Fermi wave vector associated with energy E_F. When a linear dimension of sample is comparable to Fermi wavelength λ_F ($= 2\pi/k_F$), the electron motion in that direction becomes quantized. In effect, there are changes in energy spectrum and in the dynamical properties of the system. A sample with one linear dimension comparable to (or smaller than) the Fermi wavelength is a dynamically

two dimensional system, for the electron motion is constrained in one dimension. A quantum wire and quantum dot, likewise, are systems that are constrained in two and three dimensions.

The conductance of a material whose linear dimensions are relatively greater than these length scales l, l_ϕ, and λ_F obeys the classical Ohm's law; the resistance of the conductor increases linearly as its length increases. The classical law, however, is not applicable when the linear dimension of a conductor is comparable to these length scales. These three length scales which are very important for transport processes are often used to describe the properties of localization behavior. Localization phenomena in disordered systems has been of great interest for decades.

1.1 The problem

The electrical properties of disordered systems have been studied extensively for decades. The localization effect, magnetic impurities, and electron-electron, and electron-phonon interactions are responsible for changes in the behavior of conductance. The traditional scaling theory [1] applies only for a noninteracting system at the absolute zero temperature. It predicts that the phase coherence length diverges at the absolute zero temperature [2,3]. Under such conditions, the system becomes a pure quantum system.

Recent experiments [4,5], however, show the existence of a finite coherence length scale at the absolute zero temperature. The current study is to investigate the nature of a mesoscopic conductance behavior at a finite phase coherence length.

1.2 Purpose of the Study

The study of conductance in a quasi-one dimensional system may provide some understanding of the electrical properties of nanostructures at the finite coherence length. It is interesting to observe the behavior of a length dependent conductance with a disorder and dephasing mechanism.

1.3 Objective of the Study

The objective is to simulate the effect of dephasing by attaching voltage leads at random sites of a disordered quasi-one dimensional lattice, and thereby to understand the effect of transitions between a classical and quantum system. The current study is to characterize both a classical and quantum nature of the noninteracting disordered system at the absolute zero temperature and zero magnetic field.

1.4 Outline of Work

The study of the conductance of quasi-one dimensional systems at the finite phase coherence length scale is supplemented with a study of the dephasing mechanism and the Anderson localization phenomena [6]. Anderson localization and its scaling theory have been the fundamental concepts for understanding a disordered system . A brief discussion on the conductance of the Fermi gas is reviewed for ideal crystalline structures. Although the current study is not focused on the critical phenomena, the quantum phase transition due to Anderson localization and other quantum interference effects are emphasized for further study.

The model of the study is based on the Hamiltonian (3.1) of the quasi-one dimensional lattice. The formation of the quantum wire from the two dimensional electron system is also discussed.

CHAPTER II

REVIEW OF THE LITERATURE

2.1 Quantum Wire

The construction of a quantum wire is not the objective or purpose of the study. This section only provides a method for achieving the one dimensional electron system from the two dimensional electron system. The one dimensional electron system of study can be described in terms of transverse modes or subbands [7]. Consider a plane of conductor with the confining potential $U(y)$ in zero magnetic field (see figure (2.1) below).

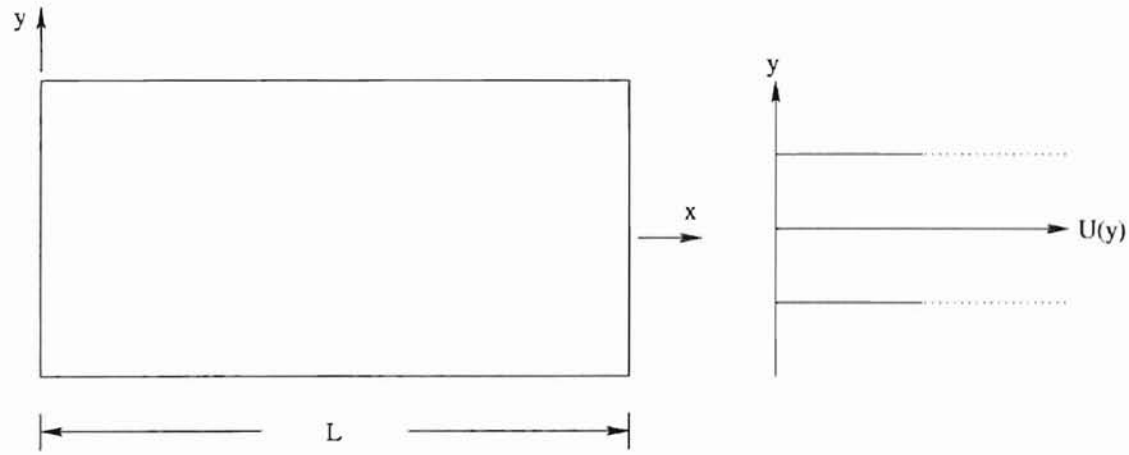

Figure 2.1. A system of conductor with some transverse confining potential $U(y)$. The electron motion is unconstrained in x direction.

The mesoscopic physics of semiconductors often deals the motion of electrons in the conduction band. The steady state wavefunction of electrons can be described by the effective mass equation:

$$\left[E_s + \frac{(i\hbar)^2}{2m}\left(\frac{\partial^2}{\partial^2 x} + \frac{\partial^2}{\partial^2 y}\right) + U(y)\right]\Psi(x,y) = E\Psi(x,y) \tag{2.1}$$

where E_s is the band-edge energy. The solution of the equation (2.1) is the form of the plane wave in x direction:

$$\Psi(x,y) = \Psi_0 e^{ikx}\Phi(y) \tag{2.2}$$

The effective mass equation (2.1) can be reduced such that it is function of y only. Let the confining transverse potential $U(y)$, for example, be a quantum well. Bound states or localized states are produced when the equation (2.1) is solved for

$$U(y) = \begin{cases} 0 & \text{if } |y| < a/2 \\ \infty & \text{if } |y| > a/2 \end{cases} \tag{2.3}$$

The localized wavefunction is finite only over some finite region in space and approaches zero at large distances. The energy eigenstates and eigenvalues can be determine exactly for the potential $U(y)$. The transverse motion can be calculated from the equation:

$$\left[E_s + \frac{\hbar^2 k^2}{2m} + \frac{p_y^2}{2m}\right]\Phi(y) = E\Phi(y) \tag{2.4}$$

The corresponding energy eigenstates and eigenvalues for $|y| \leq a/2$ are

$$\Phi_{n,k}(y) = \begin{cases} \sqrt{\frac{2}{a}}\cos\frac{n\pi y}{a} & n \quad \text{odd} \\ \sqrt{\frac{2}{a}}\sin\frac{n\pi y}{a} & n \quad \text{even} \end{cases} \tag{2.5}$$

$$E(n,k) = E_s + \frac{\hbar^2 k^2}{2m} + \frac{\hbar^2\pi^2 n^2}{2ma^2}, \qquad n = 1, 2, \ldots \tag{2.6}$$

where a is the width of a quantum well. The equation (2.5) is subject to boundary conditions such that it vanishes if $y > |a/2|$. The figure (2.2) which is represented by the parabola indicates the energy for given n.

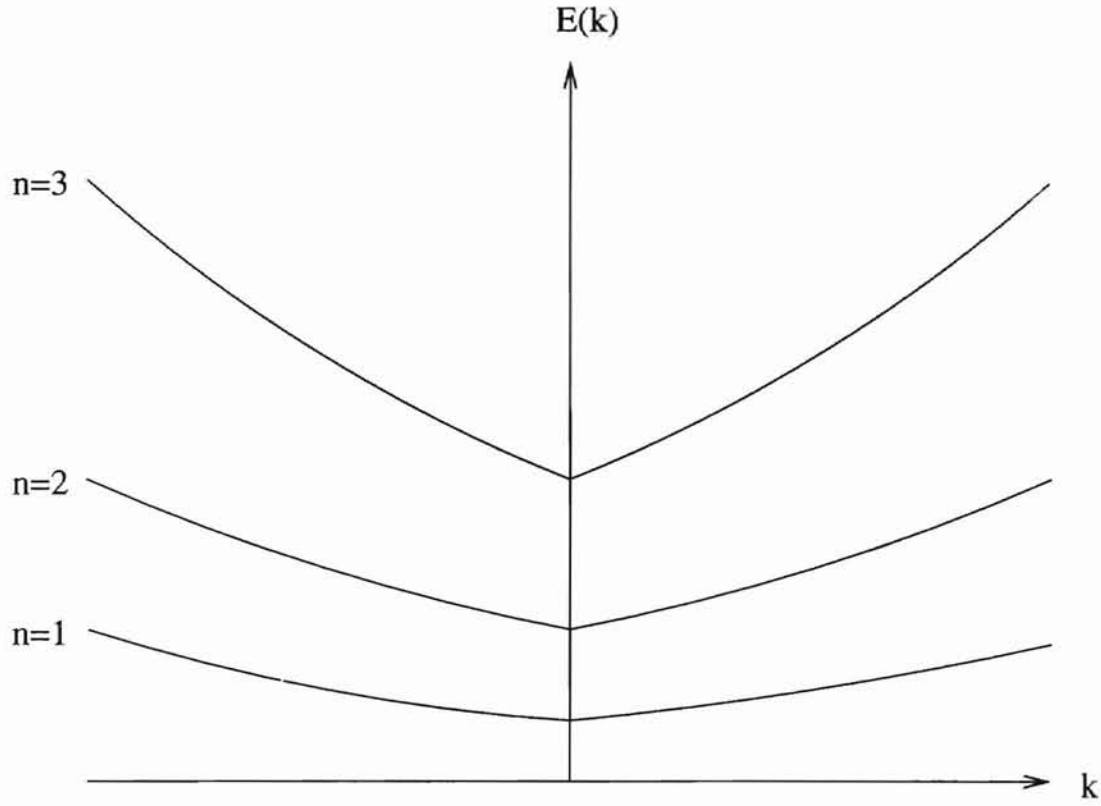

Figure 2.2. Energy-wavevector ($E(k)$ vs k) diagram shows the subbands due to electrostatic confining potential in zero magnetic field. Each subbands are labeled with the different index n.

Electrons are confined in each of the subbands at low temperatures. Thus the motion of electrons under such circumstances is restricted in transverse direction This assumption is provided that the transport takes places only in the same energy channel given n. Therefore, the two dimensional electron system becomes a dynamically one dimensional electron system.

2.2 A Noninteracting System

It is known in the classical theory of solid [8] that all energy levels are filled up to Fermi level at absolute zero temperature. When Fermi energy E_F lies in a region of localized or extended states, the three dimensional electron system becomes insulator

or metal respectively. Insulators are materials for which all energy bands are completely occupied or empty. However, metals have partially filled one or more energy bands. The conductivity of insulator at absolute zero vanishes. The conductivity of a metal in three dimension, however, obeys the classical Drude theory:

$$\sigma_0 = (ne^2/m)\tau, \tag{2.7}$$

where τ is the relaxation time (the mean free time) and n is the electron density. Since $\tau = l/v_F = ml/p_F$, equation (2.7) can be written as

$$\sigma_0 = ne^2(l/p_F) = ne^2(l/\hbar k_F) \tag{2.8}$$

The energy of an electron having a wave vector k_F at the Fermi surface is

$$E_F = (\hbar^2 k_F^2)/2m \tag{2.9}$$

Consider a free electron gas confined in a cube of the edge L, the free electron wavefunction is the form of the plane wave:

$$\psi_{\vec{k}}(\vec{r}) \propto e^{(i\vec{k}\cdot\vec{r})} \tag{2.10}$$

The equation (2.10) satisfies the periodic condition such that each of the three components of the wavevector $\vec{k}(= \frac{2\pi}{L}(n_x\hat{e}_x + n_y\hat{e}_y + n_z\hat{e}_z)$ takes the value $2n\pi/L$ (n is any integers). The total number of free electrons in Fermi sphere is

$$N = g_s \cdot \frac{4\pi k_F^3/3}{(2\pi/L)^3} = g_s \cdot \frac{V}{6\pi^2}k_F^3, \tag{2.11}$$

where g_s is the spin factor. Thus the electron density is

$$n = k_F^3/3\pi^2 = p_F^3/3\pi^2\hbar^3, \tag{2.12}$$

where $g_s = 2$ for the electron (spin $\frac{1}{2}$ particle). By substituting this expression into equation (2.8), the conductivity of a metal at absolute zero temperature then is

$$\sigma_0 = e^2 p_F/3\pi^2\hbar^2(p_F l/\hbar) \tag{2.13}$$

The Boltzmann transport theory is applicable in the weak disorder limit:

$$p_F l/\hbar \gg 1 \tag{2.14}$$

The lower limit of the conductivity can be estimated for which the Drude approximation is valid:

$$\sigma_0 = e^2 p_F / 3\pi^2 \hbar^2 (p_F l/\hbar) \gg e^2 p_F / 3\pi^2 \hbar^2 \tag{2.15}$$

Thus the minimum metallic conductivity is

$$\sigma_{min} \approx e^2 p_F / 3\pi^2 \hbar^2 \tag{2.16}$$

In strong disorder limit, the mean free path becomes of the order of lattice spacing a (microscopic length scale and $\approx k_F^{-1}$), so that $p_F l/\hbar \sim 1$. Consequently, the usual Boltzmann transport equation becomes inapplicable. The minimum metallic conductivity does not depend on either the lattice structure or the nature of disorder.

2.3 Scaling Theory of Localization

Most real materials contain impurities. The energy levels and wave functions of electrons in disordered materials generally differ from those in an ideal materials. In pure crystalline structure with a periodic potential, the electron wave function is easily described by Bloch functions. In weak disorder, although the wave function alters at the scale of the order of mean free path l, the scattering of Bloch wave typically remains extended plane-wave-like. The concept of electron localization is essential for understanding disordered materials.

Metal-Insulator transition (MIT) is the transition state where the wave function goes from being extended (Bloch wave-like) to being localized. The limit of disorder is crucial for understanding the critical phase transition from metallic to insulating states. Anderson localization [6] profoundly describes the nature of the wave function of a single electron which scatters by a random potential. In the Anderson model, the disorder is brought about by varying the random site potential energy. The random potential acts as a mirror such that the initial momentum of a electron $\vec{p}$ ends up with its final momentum being $-\vec{p}$, and the consequent backscattering of the electronic wavefunction leads to a spatial localization. It has been well known that the state of the electron can be localized due to a strong disorder. In this case, the amplitude (envelope) of the wave function decreases exponentially from the center of

localization $\vec{r'}$, i.e.,

$$|\psi(\vec{r})| \sim e^{-(|\vec{r}-\vec{r'}|)/\xi}, \tag{2.17}$$

and ξ is the localization length.

The physical interpretation of localization can be described by coherent tunneling. However, Anderson localization states that no such tunneling is possible at absolute zero temperature, for states with the same energy are generally too far in space.

The above microscopic description of Anderson localization leads to its consequent scaling theory. The scaling theory of localization [1,2] which is based on the one-parameter scaling assumption is valid for a noninteracting electron system at absolute zero temperature ($T = 0$) and zero magnetic field ($B = 0$). The main physical idea is that the transformation of parameters of the initial Hamiltonian is approximated by a series of scale transformations from smaller to larger blocks in coordinate space. The conductance G of a macroscopically homogeneous conductor of a d-dimensional hypercube of linear dimension L in the limit of weak disorder ($p_F l/\hbar \gg 1$) is

$$G(L) = \sigma L^{d-2}. \tag{2.18}$$

It is assumed that $L > l$, so that the classical Ohm's law ($\vec{j} = \sigma\vec{E}$) is valid. It can then be normalized by the quantity $e^2/\hbar$, so equation (2.18) can be expressed in the dimensionless conductance of hypercube as

$$g(L) = \frac{G(L)}{(e^2/\hbar)}. \tag{2.19}$$

In scaling theory, it is assumed that the dimensionless conductance $g(L)$ solely determines the conductivity behavior of a disordered system.

The coherent electronic transport takes place between states of the system with the same energy. Since the degenerate states, however, which are in the limit of strong disorder are very far apart in space, the transition (hopping) matrix elements between different electronic states drop exponentially on the order of localization length ξ. The effective conductance for $L \gg \xi$ is then exponentially small:

$$g(L) \propto exp(-L/\xi) \tag{2.20}$$

The conductance of a hypercube of length L generally satisfies the one-parameter differential scaling function β:

$$\beta(g(L)) = \frac{d(\ln g(L))}{d(\ln L)} \tag{2.21}$$

For $\beta(g(L)) > 0$ (metallic state), the conductance of the block of length L will increase upon enlarging the system, and visa versa for $\beta(g(L)) < 0$ (insulating state). In other words, the scaling function β describes the phase transition of the finite electron system that is scale length dependent. Equation (2.21) thus describes the transport properties at that degree of disorder in the limit of infinite volume.

In the metallic regime, the limiting behavior of the scaling function can be calculated from equation (2.18):

$$\beta(g) = d - 2, \qquad g \gg 1 \tag{2.22}$$

An asymptotic limit depends only on the dimensionality of the system. $\beta(g)$ vanishes in two dimensional system; the conductance is independent of its size. In the insulating regime, the scaling function is derived from equation (2.20):

$$\beta(g) = \ln g + c, \qquad g \ll 1 \tag{2.23}$$

where c is a constant. It is independent of the dimensionality of the system.

The scaling function $\beta(g)$ is a monotonous nonsingular function connecting the two asymptotic limits. In three dimensions, MIT occurs at some critical conductance g_c such that $\beta(g_c) = 0$. However, based on the one parameter scaling argument, two dimensional systems exhibit insulating behavior since $\beta(g) < 0$ as it is in one dimension.

In contrast to the traditional scaling theory, a recent experiments and theories [10–19] clearly show the existence of Metal-Insulator Transition in two dimensional electron systems. Based on these experimental results, the electron density is the key parameter which determines the phase transition between two distinct phases; states whose densities are lower or higher than some critical density are localized (insulator) or extended (metal). It is surprising to discover that the resistivity of these high

mobility samples at low densities decreases approximately an order of magnitude as temperature decreases. The resistivity obeys the empirical law:

$$\rho(T) = \rho_0 + \rho_1 exp(-(T_0/T)^p) \tag{2.24}$$

where $p \sim 1$. This remarkable evidence contradicts the long held belief in the scaling theory of localization [1].

2.4 Dephasing

The quantum interference effect in mesoscopic system may alter the phase coherence of the electronic wavefunction. The coherent transport keeps the record of the initial phase of all single electron wavefunctions. On the other hand, dephasing refers to a noncoherent transport which loses all phase memory. A complete loss of phase information on the system is equivalent to a collision process that changes the state of environment. This is true when the possibility of recovering the effects of phase coherence by the environment is neglected.

CHAPTER III

METHODOLOGY

3.1 Method of Computing the Total Conductance

The method of the study is to use a tight binding Hamiltonian to simulate a quasi-one dimensional lattice,

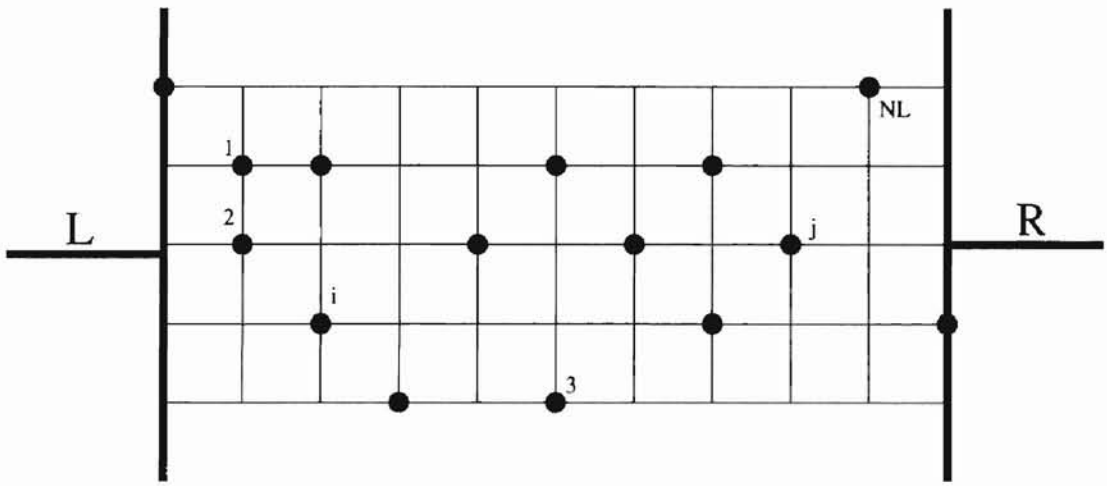

Figure 3.1. - Lattice system of the study. • denotes a lattice site where a phase-breaking voltage lead is attached.

A figure (3.1) represents a quasi-one dimensional lattice system of five channels. The width is assumed to be much smaller than the length of the lattice system. The model for the study is based on the Anderson model (or a nearest neighbor tightbinding model) of a quasi-one dimensional lattice system,

$$\mathcal{H}_\alpha = \sum_i \epsilon_i c_i^\dagger c_i + \sum_{ij} t_{ij}(c_i^\dagger c_j + c_j^\dagger c_i) \tag{3.1}$$

where the c's represent fermion creation and annihilation operators and where the electron spin is ignored. The static disorder is introduced by taking ϵ_i (on site energies) and t_{ij} (the nearest neighbor hopping matrix element) to be random. A

random energy ϵ_i is uniformly distributed in the range $-W/2$ to $W/2$. The hoping matrix element assumes the value 1 for i,j nearest neighbors and zero otherwise. For n lattice sites, the summation index i and j $(i \neq j)$ in equation (3.1) runs from $i, j = 1, 2, 3, \cdots, n$. It is assumed that there is only one orbital per site. The subscript α denotes the dimensionality of the Hilbert space which depends on a numbers of lattice sites. The dephasing mechanism [7] in this model is brought about by attaching current-conserving voltage leads at random lattice sites ($\bullet$ sites in Fig. 3.1).

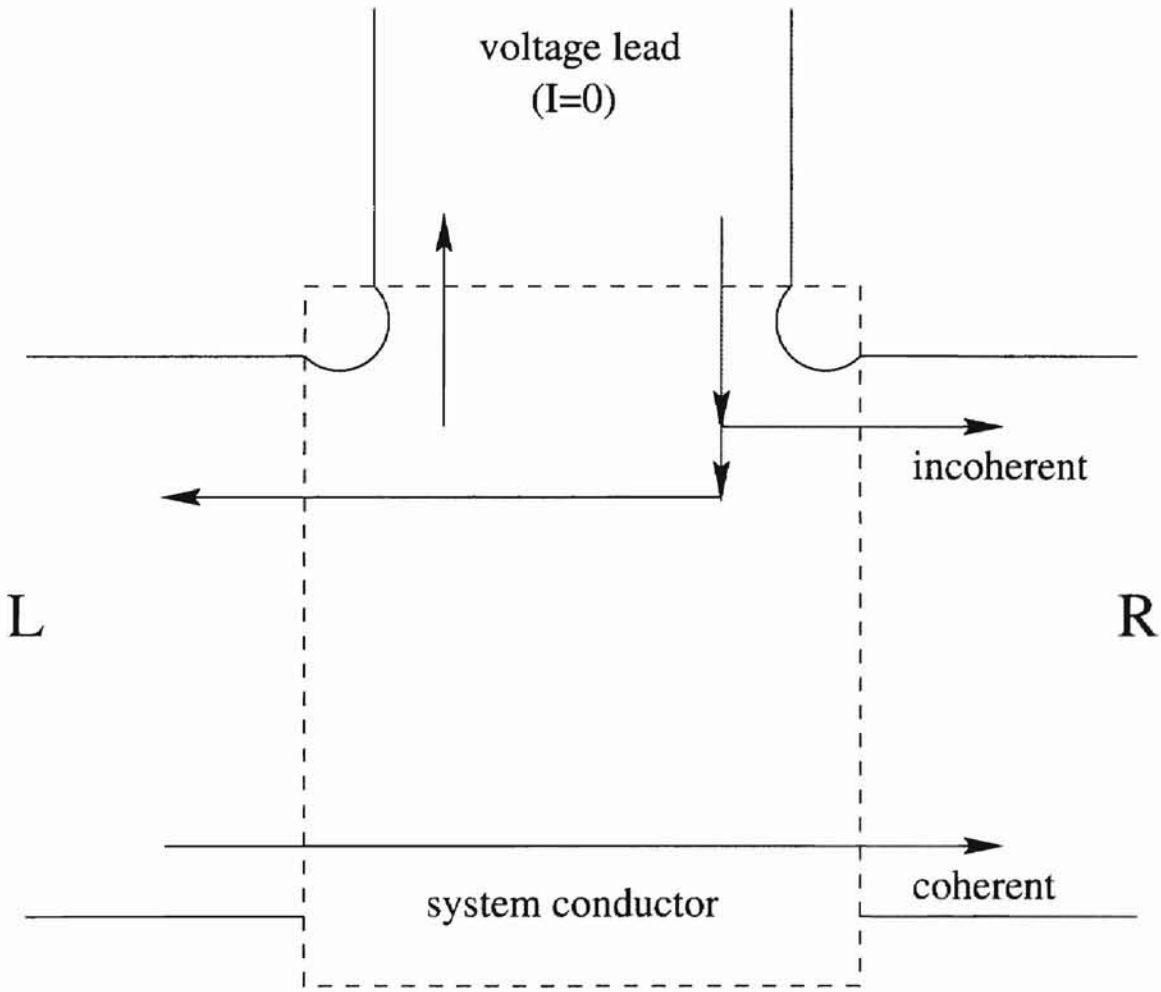

Figure 3.2. The net current flows from L to R through the conductor that is attached to a voltage lead.

The voltage lead is attached to the noninteracting system in order to randomize the phase of the coherent transport. The figure (3.2) above illustrates the phase-breaking process. Consider the net current flows from L to R with initial phase

coherence. Part of the electrons make a smooth transition to L without loosing coherence. The remaining electrons find a path to the voltage lead. Since the total sum of all current at the voltage is assumed to be zero, electrons that enter the voltage lead lose their coherence; electrons are then reinjected to the system conductor. Some of reinjected electrons reache R, and the rest flow back into L.

There are four parameters which are important in current study. Parameters for dephasing mechanism are P_v and t_v. P_v is the probability for the voltage lead. $P_v = 0.1$, for example, indicates that 10% of lattice sites have attached to voltage leads. t_v is the coefficient for hopping between the lattice and voltage lead. The disorder in this study is controlled by the parameter W which represents the amount of disorder. The last quantity is the energy eigenvalue E associated with the electron.

The multi-lead current-voltage relation is derived [10] using Keldysh formalism [7]:

$$I_i = \sum_{i=1}^{N} L\sigma_{ij}V_j, \qquad i,j = L,R,1,2,\cdots,NL, \tag{3.2}$$

where the conductance tensor is

$$\sigma_{ij} = \frac{8e^2}{\hbar}\mathrm{Tr}[(T_{j\alpha}G^r_{\alpha\alpha}T_{\alpha i})\rho_i(T_{i\alpha}G^a_{\alpha\alpha}T_{\alpha j})\rho_j], \qquad i \neq j, \tag{3.3}$$

and

$$\sigma_{ii} = -\sum_{j\neq i}\sigma_{ij} \tag{3.4}$$

For n lattice sites, the $n \times n$ matrix representation of Green's function is

$$G^r_{\alpha\alpha} = \left[E - H_\alpha - \sum_{i=1}^{NL,L,R} T_{\alpha i}g^r_i T_{i\alpha}\right]^{-1} \tag{3.5}$$

where $T_{j\alpha}$ ($T_{\alpha i}$) represents the $n \times N$ ($N \times n$) matrix elements. In general, N is the number of channels per voltage lead, but $N = 1$ for the current simulation. The hopping matrix elements $T_{j\alpha}$ are non zero ($= t_v$ (the coefficient for hopping between voltage leads and lattice system)) if jth lead and lattice sites are connected and zero otherwise. $G^{r(a)}_{\alpha\alpha}$ ($G^a_{\alpha\alpha} = [G^r_{\alpha\alpha}]^\dagger$), and $\rho_i = Img^a_i$ (g^a_i is the advanced Green's function of the i'th voltage lead) are retarded (advanced) Green's function of the lattice system, and density of states matrices for the voltage leads and measurement leads L and R.

$G^r_{\alpha\alpha}$ can be visualized as the amplitude of an arbitrary path from j to i. It is assumed that the total sum of currents through the ith voltage lead to be zero:

$$I_i = 0, \qquad i \neq L, R \tag{3.6}$$

The total conductance between L and R is

$$g = \sigma^d_{LR} + \sigma^i_{LR} \tag{3.7}$$

where σ^d_{LR} is the direct conductance (can be determined from equation (3.3) by setting $i = L$ and $j = R$), and σ^i_{LR} is the indirect conductance:

$$\sigma^i_{LR} = -\begin{pmatrix} \sigma_{L1} & \cdots & \sigma_{LN} \end{pmatrix} \begin{pmatrix} \sigma_{11} & \cdots & \sigma_{1N} \\ \vdots & \ddots & \vdots \\ \sigma_{N1} & \cdots & \sigma_{NN} \end{pmatrix}^{-1} \begin{pmatrix} \sigma_{1R} \\ \vdots \\ \sigma_{NR} \end{pmatrix} \tag{3.8}$$

The direct conductance σ^d_{LR} represents the the direct quantum hopping (a coherent transport) between the measurement electrodes. The indirect conductance, which is the conductance of the qauntum lattice model, accounts for the sequential hopping (a noncoherent transport).

3.2 Research Methodology

The simulation is based on the original percolation program [10], and that program is modified such that all the nearest neighboring sites are occupied in the quasi-one dimensional lattice for the current research. The systematical Monte Carlo simulations were done by varying P_v (the probability for a voltage lead), t_v (the coefficient for hopping between a voltage lead and the lattice system), W (on-site disorder), and E (the electron energy). In each simulation runs, the Monte Carlo method simply selects random sites for given parameters. The program then calculates the equations (3.5), (3.8), (3.3), and (3.7). For N' runs, the average conductance is

$$\bar{g} \simeq \frac{1}{N'} \sum_{n=1}^{N'} g'$$

3.3 Research Instruments

The computer simulation has performed on IBM compatible PC. The program is written and compiled using Fortran 77.

CHAPTER IV

Results and Discussions

4.1 Methodology

Two and five channels in the quasi-one dimensional lattice systems are studied under the influence of localization and dephasing effects. The consistent method of simulations on two and five channels is used to obtain the data. The ensemble of the data for two and five channels is then expected to give the average effect or result of analysis. Data which is collected by computer simulation reflects the localization and dephasing effect on conductance (or resistance) at finite phase coherence length. The total conductance (resistance) g (g^{-1}) is contributed by both the quantum and classical behavior. The phase coherence length scale l_ϕ is approximately determined by inspecting where the signature of the resistance $g^{-1} \propto L^{2-d}$ (where $d \simeq 1$ for a quasi-one dimensional lattice system) starts.

4.2 Chapter Overview

Data are plotted for the total resistance ($g^{-1}(h/e^2)$) versus the system length scale L. A figure corresponding each variation of parameters are separated by each sections. Figures in the following sections are corresponding to four parameters.

4.3 Variation of the probability for a voltage lead

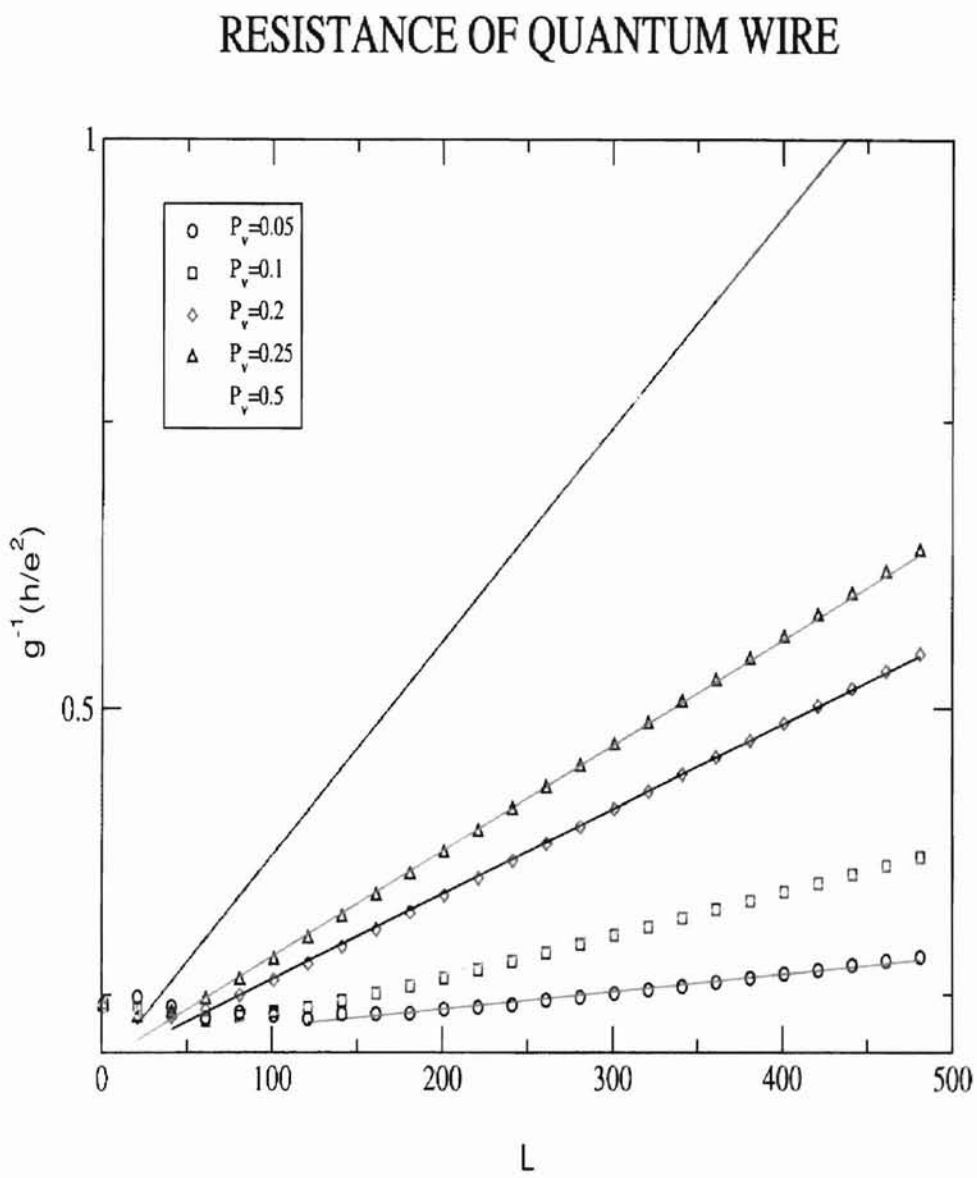

Figure 4.1. two channels at $t_v = 0.4$, $W = 0.1$, and $E = 0.0$

The figure (4.1) shows the the total resistance versus system length scale for variation of the probability of the voltage lead P_v for two channels. The phase coherence length scale is the approximately the length scale in which the length dependent resistance does not obey the classical law (see equation (2.18)). It clears shows that the phase coherence length l_ϕ decreases as P_v increases. The phase breaking voltage leads mainly effects the quantum regime on resistance.

RESISTANCE OF QUANTUM WIRE

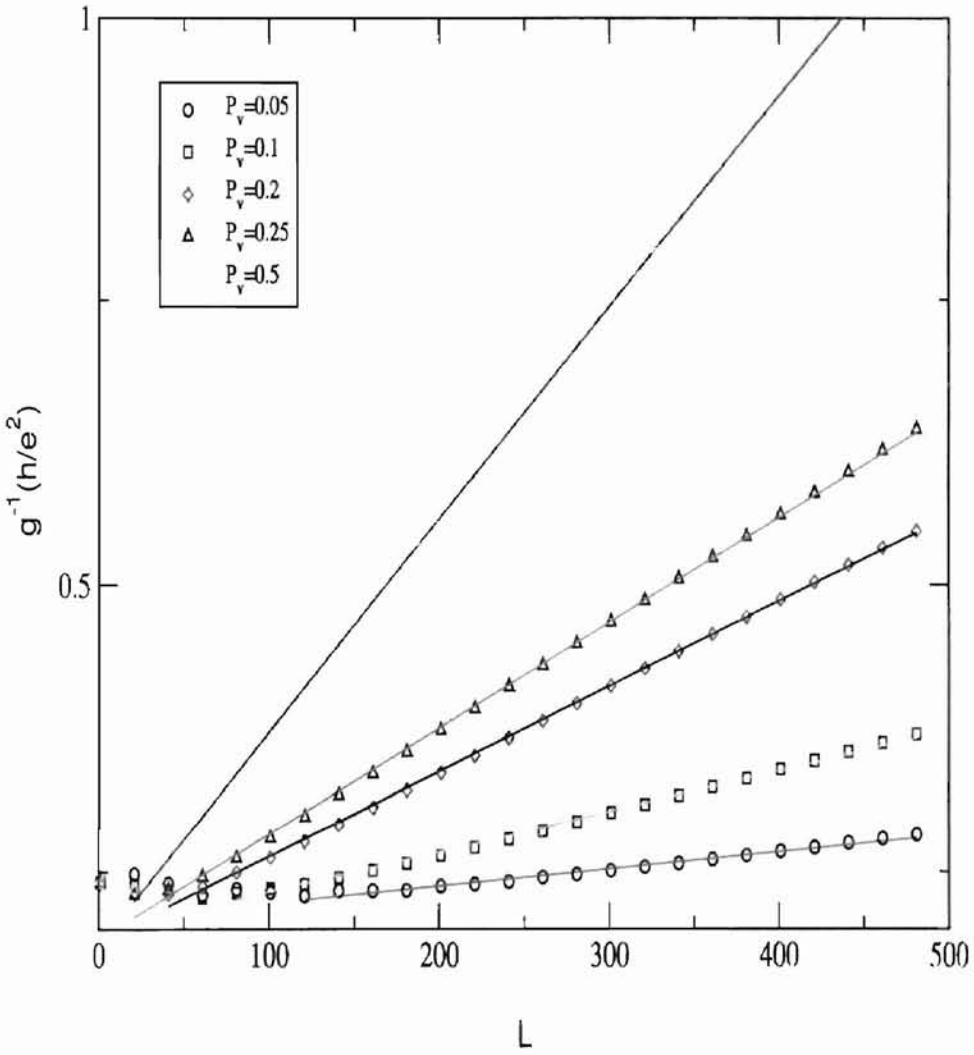

Figure 4.2. five channels at $t_v = 0.4$, $W = 0.1$, and $E = 0.0$

The figure (4.2) shows the same dependence on L for five channels as for two channels (see figure (4.1).

4.4 Variation of on-site disorder

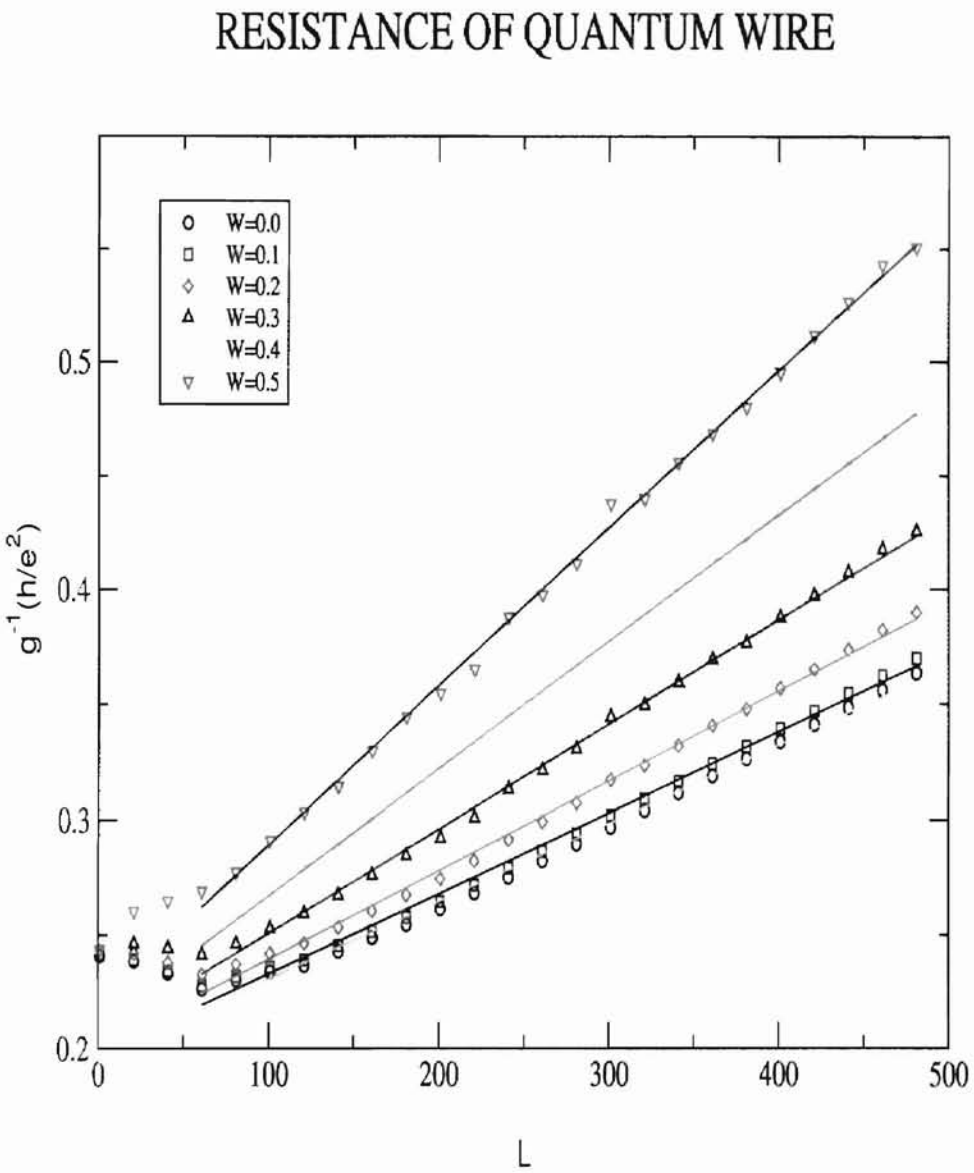

Figure 4.3. two channels at $t_v = 0.4$, $P_v = 0.1$, and $E = 0.0$

The figure (4.3) shows that the variation of on-site disorder W hardly influences on the conductance of the system of two channels. The presence of the amount of disorder is small such that the quantum regime is dominated by the dephasing effect.

RESISTANCE OF QUANTUM WIRE

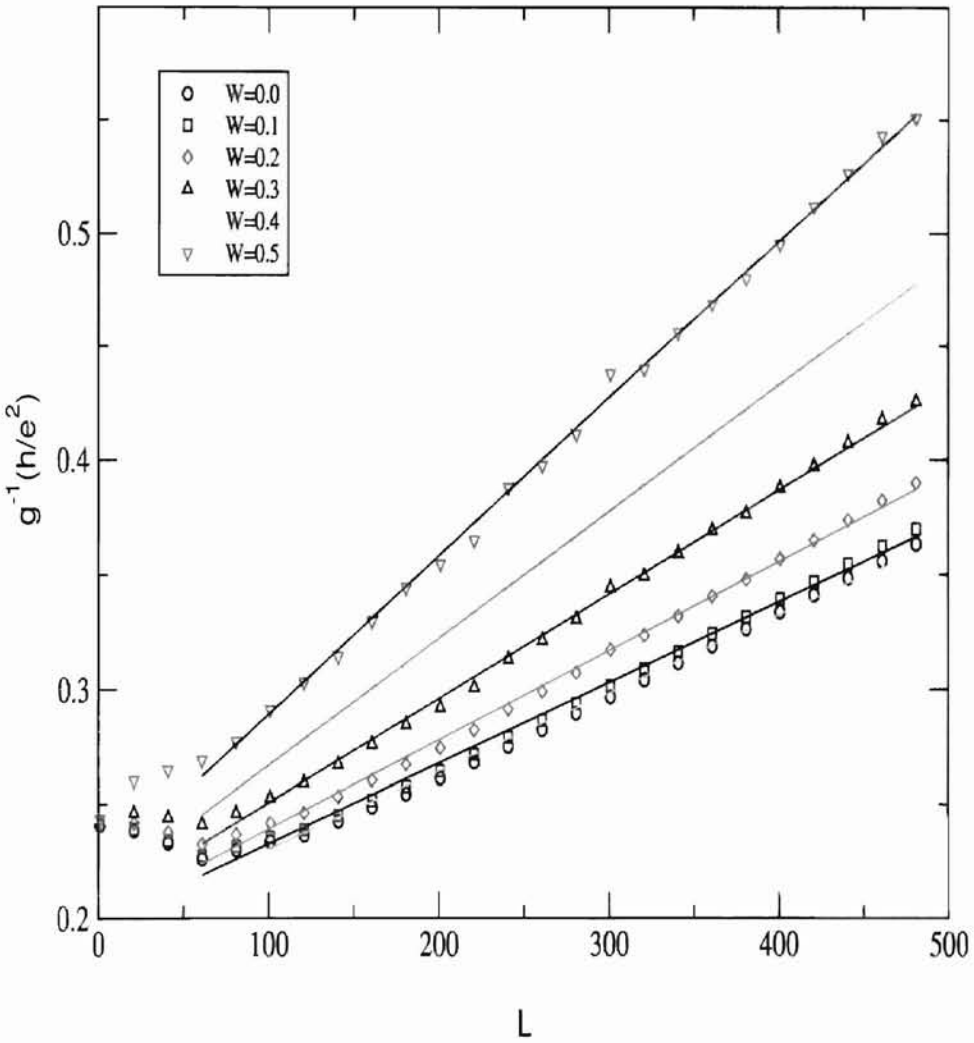

Figure 4.4. five channels at $t_v = 0.4$, $P_v = 0.1$, and $E = 0.0$

The figure (4.4) indicates the effect on the conductance of five channels; the results almost coincide with the case of two channels (see figure(4.3)).

4.5 Variation of the coefficient for hopping between a voltage lead and lattice system

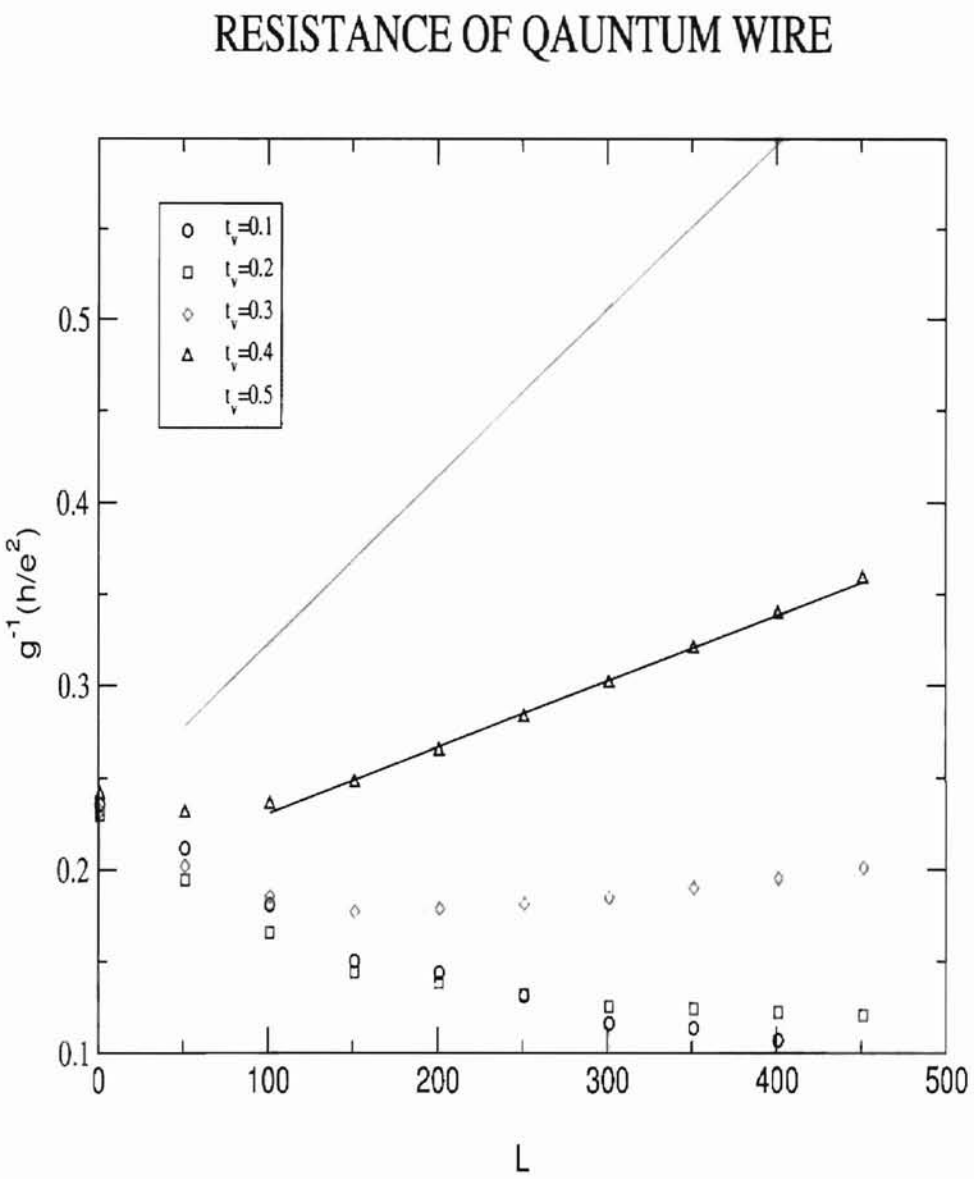

Figure 4.5. two channels at $W = 0.1$, $P_v = 0.1$, and $E = 0.0$

The figure (4.5) shows that the phase coherence length l_ϕ decreases with the higher t_v (the coefficient for hopping between a voltage lead and the lattice system) for two channels. t_v is another also a phase breaking source. For $t_v = 0.1, 0.2$, it is noted from the equation (2.20) that the localization length scale ξ is much greater than the system length L.

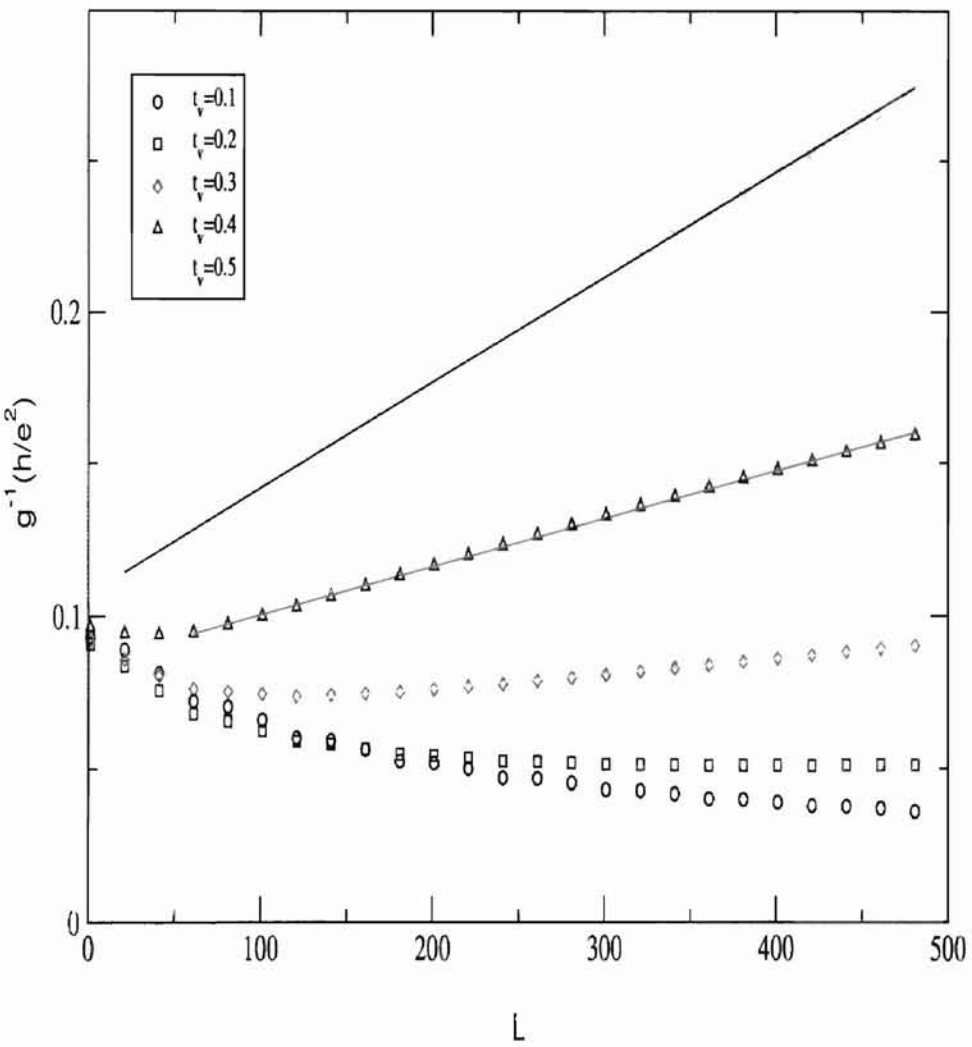

Figure 4.6. five channels at $W = 0.1$, $P_v = 0.1$, and $E = 0.0$

The figure (4.6) show the similar results for five channels.

4.6 Variation of the electron energy

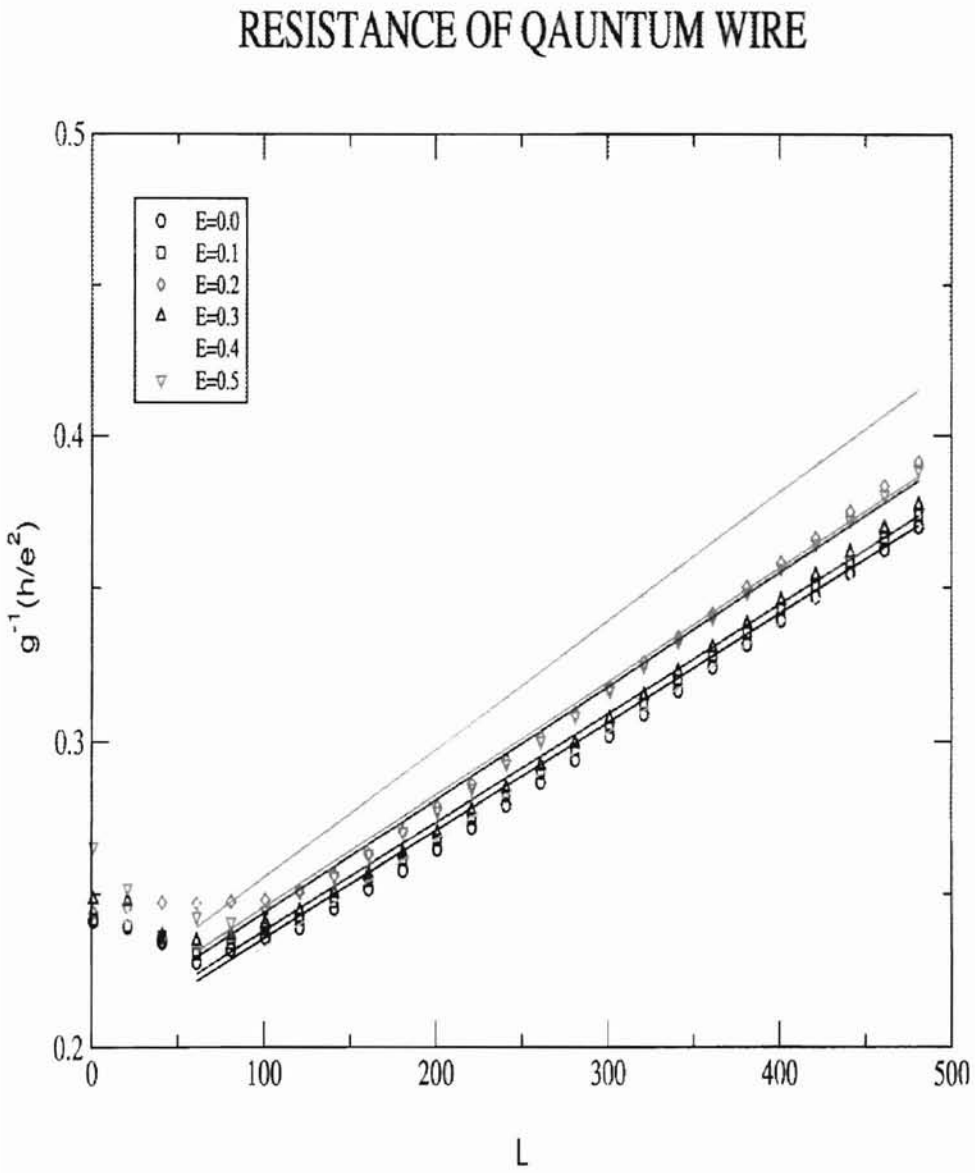

Figure 4.7. two channels at $W = 0.1$, $P_v = 0.1$, and $t_v = 0.4$

The figure (4.7) shows that the effect of varying the electron energy is negligible compared to the effects due to a dephasing parameters.

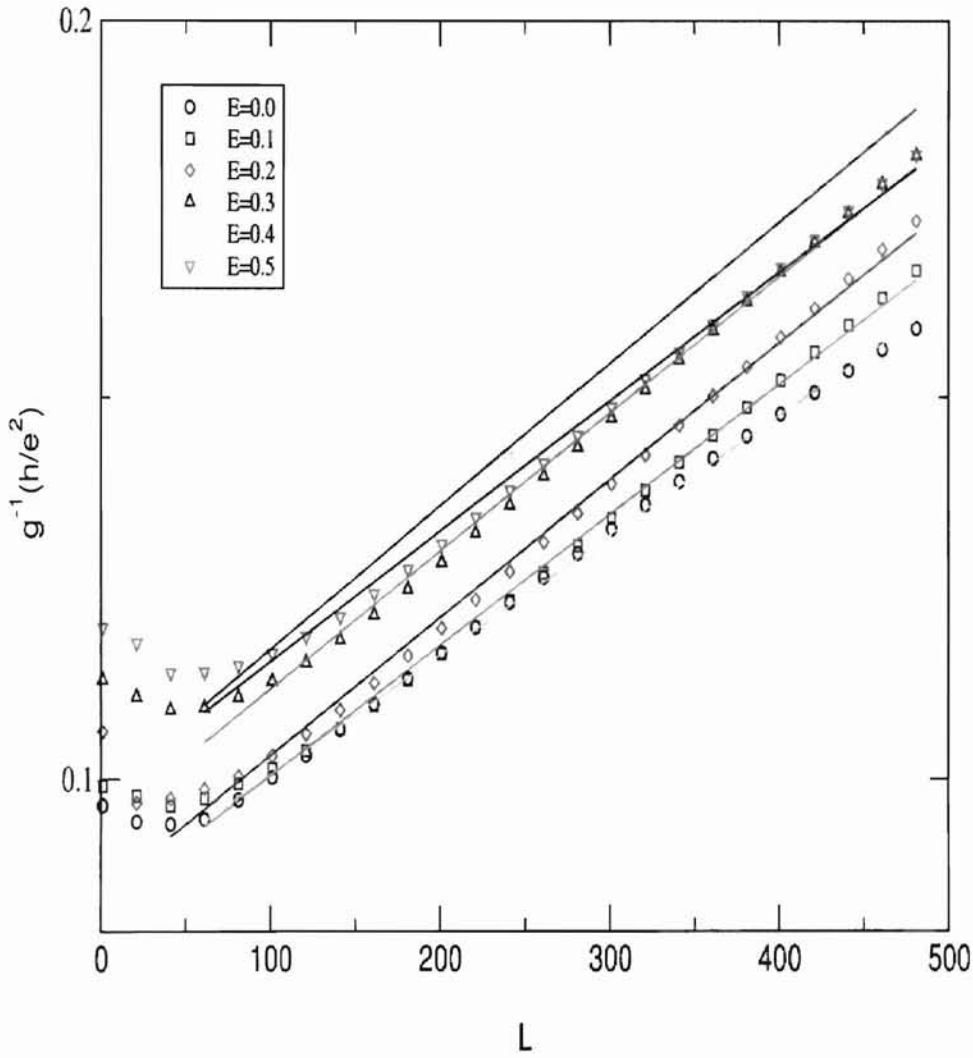

Figure 4.8. five channels at $W = 0.1$, $P_v = 0.1$, and $t_v = 0.4$

The figure (4.8) shows the similar behavior for five channels.

CHAPTER V

CONCLUSIONS

5.1 Discussion of Research Findings

The phase coherent length l_ϕ is effected mainly by parameters P_v and t_v. These are responsible for the phase-breaking mechanism in the model of the study. The contribution from the amount of disorder W and electron energy E are negligible compared to P_v or t_v. The exact relationship between l_ϕ, P_v, and t_v is not determined yet. As P_v decreases at constant t_v, the system evolves to a pure quantum system ($l_\phi \longrightarrow \infty$). The quantum regime on resistance is dominated by mainly by the phase breaking effect rather than the localization effect. In the absence of the dephasing parameters P_v and t_v, the system becomes the pure quantum system; the resistance of the quantum system increases exponentially on L.

5.2 Summary and Conclusion

The phase coherence l_ϕ, based on the current data, defines the the cutoff length scale beyond which the resistance ($g^{-1}(h/e^2)$) of the system increases linearly with increasing the system length L. For $L < l_\phi$, the conductance has to be determined quantum mechanically. In the opposite limit, the classical transport is valid. A real conductor whose length is much greater than the phase coherence length l_ϕ, it could be viewed as the average many coherent segments $N = L/l_\phi$ [7]. Each segments then can be treat as a single resistor R. Defining a resistance R for the segment, the total resistance $R_{tot}(L)$ of the system length L is obtained by summing the series elements of resistors. The total conductance $g(L)$ then is just inverse of $R_{tot}(L)$.

For interacting electron system, the phase breaking is caused by electron-electron and electron-phonon interaction. In such system, the phase coherence length

depends on temperature ($l_\phi(T) \propto T^{-p}$) [2,3] and diverges at absolute zero temperature.

However, the recent experiments and theories suggest the existence of the finite phase coherence length at absolute zero temperature [4,5] to which the current study may be applicable. The effect of dephasing, based on the result, clearly shows the deviation from the pure quantum system.

The quantum interference effects are essential for determining the transport properties of low dimensional electron system and are responsible for the conductance fluctuations as the Fermi wavelength of the electrons changes.

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