Author: Kumar, Manohar
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A STUDY OF ELECTRON SCATTERING THROUGH NOISE SPECTROSCOPY

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Manohar KUMAR

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Science is a wonderful thing
if one does not have to earn one's living at it.

Albert Einstein

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PREFACE

When the miniaturization of an electronic circuit reaches the scale of single molecules we arrive in a regime dominated by quantum effects. In laboratory experiments, such systems often are made up of a single organic molecule, or a group of metal atoms, bridging two metallic leads. Unlike bulk metals the flow of the electrons here is dominated by the local potential landscape of the molecules or the atoms through which the electron is flowing. Interaction of the conduction electrons with these low dimensional local species, *i.e.* atoms or molecules, reveals their inherent properties. Many properties have been predicted to play a role, such as local vibration modes, the Frank Condon effect, mechanical shuttling, and many body effects such as the Kondo effect. Many of these have been studied experimentally on atomic and molecular systems. Most previous studies have been limited to current - voltage spectroscopy, *i.e.* to the measurement of conductance. The conductance is a time averaged property of the system. It can be viewed as the first moment of the probability distribution of the effective charge being transmitted during the measurement time. The second moment, which measures the spread of this probability distribution from its mean value, provides information which is not present in the mean value. In electron transport physics this second moment is known as shot noise. Hence, the famous quote by Rolf Landauer is very appropriate: "*The noise is the signal*". Hence, noise spectroscopy has become one of the focus themes in nanoelectronics and nanophysics.

Two widely discussed concepts which have been a delight for physicists are electron - electron interactions and electron - vibron interactions. Both of these interactions have been much studied in various atomic and molecular systems. However, most of these studies have been limited to differential conductance spectroscopy. Electron transport in atomic and molecular systems is quite rich and lots of new phenomena have been predicted related to the two interactions mentioned. Our experimental studies here are concerned with new exciting features related to these interactions. Here we have combined both, conductance and noise spectroscopy, to study these effects.

An electron traversing the bridging atom or molecule in a contact has a finite probability of interacting with the local vibrons. This interaction is often observed in a measurement of the differential conductance as a step upward, or a step downward, depending on the transmission probability and other details of the conductance channels. Shot noise, being the second moment of the electron transmission distribution, is more sensitive to this interaction. Shot noise is expected to show deviations from the classical Lesovik-Levitov noise for bias voltages above the vibron energy. For simple systems with a single conductance channel this inelastic correction in the noise has been predicted to change sign at a transmission probability $\tau \simeq 0.15$ and at $\tau \simeq 0.85$. Our shot noise studies here are limited to the inelastic correction in noise around the higher transmission cross-over value $\tau \simeq 0.85$. Since most shot noise studies on atomic or molecular conductors are affected by $1/f$ noise we have developed a noise setup operating at high frequencies(300kHz – 10MHz), which permits the study of noise in simple molecular systems like Pt-D_2-Pt and Au-O-Au.

The force acting on the atoms or molecules by traversing electrons has been recently highlighted by theoretical work which demonstrated that this force is non-conservative. This has led to interesting developments in the fundamentals of electron transport. The non-conservative force acts specifically on nearly degenerate orthogonal vibration modes, which gives rise to "runway modes" at high currents. The force leads to high amplitude oscillations of the atom or molecule in the contact which eventually causes its break down. Until today these concepts have only been formulated theoretically and no quantitative experimental tests have been reported. Here, we have performed preliminary studies of anomalous noise properties in Au atomic contacts and discuss these in relation to the predicted effects due to non-conservative forces.

Magnetism plays a central role in much of condensed matter physics, be it itinerant magnetism or localized magnetic moments, and its interest is tightly connected to applications, such as data storage. The control and read-out of the magnetism of a single atom can be seen as the holy grail of data storage technology. It has been long predicted that some non-magnetic transition metals such as Pt, Pd and Ir, should undergo a transition to a ferromagnetic state upon reduction of the atomic co-ordination number, due to the resulting increase in the density of states at the Fermi energy. Specifically, long Pt atomic chains have been predicted to become magnetic upon stretching, but to date there have been no experimental observations that directly demonstrate itinerant magnetism in Pt atomic chains. Here, we have studied conductance and shot noise for this system in order to probe into the magnetic order of the itinerant electrons.

At the other extreme of magnetism we find localized magnetic moments. Recent studies by Calvo *et al.* on ferromagnetic atomic contacts have shown resonance features near zero voltage bias and these were attributed to the Kondo effect. This was quite unexpected because the Kondo effect is normally associated with inhomogeneous states, with one type of electron system providing the itinerant electrons and the other providing a localized magnetic moment. The Kondo effect in an atomic contact made up of all the same ferromagnetic metal atoms was quite a new concept. Our noise studies on $s-d$ and $s-p$ itinerant atomic and molecular systems form an extension of the work by Calvo *et al.*

This thesis forms a small step towards further understanding of electron transport in atomic and molecular conductors. Noise studies on these systems reveal minuscule perturbations in electron transport, and show the potential of noise spectroscopy in molecular electronics research.

Manohar Kumar
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