Chapter 1

NONLINEAR PHENOMENA IN METALLIC CONTACTS

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Abstract We review and extend theoretical approaches to nonlinear and nonequilibrium effects in metallic microcontacts ranging in their dimension from the atomic to macroscopic sizes. Atomic contacts are shown to quantize their conductance in units of $2e^2/h$ provided the charge redistributes near the constriction to establish the maximal electron transmittivity through the orifice. Ballistic semiclassical contacts are treated both from the Landauer point of view and from the Boltzmann transport theory. The $J-V$ nonlinearity in contacts is related to the inelastic scattering near the narrowest part of the constriction and permits for spectroscopic investigation of phonons in solids (the point-contact spectroscopy). The effects of phonon emission and reabsorption in contacts are taken into consideration. Phonon relaxation is shown to determine the frequency dependence of the nonlinear contact conductivity. Thermal contacts develop specific nonequilibrium states with hot spots in the center of metallic constriction whose temperature is much in excess of the ambient contact temperature and is uniquely related to voltage.

1. INTRODUCTION

It is the aim of this paper to present a coherent approach to linear and nonlinear, as well as to equilibrium and nonequilibrium, phenomena in metallic contacts of diameter ranging from the atomic size to macroscopic size. Our understanding of these properties arises from the works of Landauer [1], Sharvin [2], Yanson [3], Holland groups [4, 5], and others [6], etc. Unlike tunneling junctions, direct metallic constrictions (or links) develop a number of peculiarities of which we mention the following.
(1) Conductance of contact scales with the quantum of conductance

\[ G_0 = \frac{2e^2}{h} = 1/12.9 \text{k} \Omega \]  \hspace{1cm} (1.1)

in such a way that minimal conductance reaches a value \( G_0 \) before the contact breaks to the tunneling-type junction with a much smaller or zero conductance, and is even quantized in units of \( G_0 = R_0^{-1} \) in a proper arrangement. In particular, this happens if contact size or shape is varied by applying a gate voltage to change the electron concentration (in semiconducting constrictions), or contacting electrodes are pulled away to increase the length (and possibly the contacting area), in metallic contacts. The typical dependence of the contact conductance on the pulling strength [7] is presented in Fig. 1.1.

![Figure 1.1](image)

**Figure 1.1** Conductance of sodium contact at 4.2 K as a function of stretch [7]. Measurements have been performed by pressing two pieces of metal and then pulling them away from one another with a piezoelectric sensor. Reproduced by permission from Ref. [7].

(2) The electron flow in a constriction is a regular quantum process (a kind of “nondemolition measurement”) while the energy dissipation takes place away from its narrowest part. Because of this, the shot noise in direct metallic constriction reduces compared to its value in the tunneling junction of similar resistance [8]

\[ S_V \sim 2eV R \frac{d}{l} \]  \hspace{1cm} (1.2)

where \( S_V \) is the shot noise power and \( l \) the phase-breaking electron mean free path assumed to be larger than the contact diameter \( d \). Reduced