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Low-temperature resistance fluctuation in disordered conductors

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Abstract. At low temperatures the electron elastic mean free path in a disordered conductor can become much smaller than the inelastic mean free path (or more precisely the Thouless length) which in turn may be comparable with, or even larger than the sample size. In this quantum regime, the electrical resistance is dominated by the coherence effects that eventually lead to the now well-known weak or strong localization. Yet another remarkable manifestation of the quantum coherence is that it makes the resistance non-additive in series and, more importantly, non-self averaging, thus replacing the classical Ohm's law with a quantum Ohm's law describing statistical fluctuations. In this paper, we report on some of our recent work on the statistics of these "Sinai" fluctuations of residual resistance for one and higher space dimensions (d). In particular we show that the physics at the mobility edge may be dominated by these fluctuations. We also show that an external electric field tends to harness these fluctuations. Some observational consequences such as $1/f$-noise at low temperatures are discussed. Our approach is based on invariant imbedding extended by us for this purpose.

Keywords. Disordered conductors; low-temperature resistance fluctuation; residual resistance; mobility edge; Sinai fluctuations.

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1. Introduction

Theoretical physics of disordered systems frequently involves a convenient artifice of averaging of physical quantities of interest over the probability distribution of the underlying quenched randomness which is assumed to be given. This is despite the fact that the experiment is performed on a *given* sample. The rationale for this mathematical artifice is that for a macroscopic sample, i.e., in the thermodynamic limit, different parts of the sample may be taken as different instances of the sample. Thus, if the quantity of interest is extensive i.e., expressible as an integral of a local density over the sample volume, then the observed value is reproduced by the ensemble averaging which then becomes a matter of convenience. There are, however, quantities which are not self-averaging in the above sense. Well-known examples are from the statistical mechanics of disordered systems, e.g., the archetypal spin glass. Here the partition function and several susceptibilities are in fact not self-averaging, but the free energy is. In the following we will be concerned with the (residual) resistance of a disordered conductor at low temperatures which is dominated by quantum coherence effects (Kumar 1985; Kumar and Jayannavar 1986; Kumar and Mello 1985). The latter will be shown to make the resistance non-additive and non-self averaging. This was already noted for the case of one-dimensional conductors by Mel'nikov (1980), Anderson *et al* (1980) and Abrikosov (1981). Following an invariant imbedding procedure, we derive an expression for the probability