

Noise insights into electronic transport

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Submitted 8 May 2018
Resubmitted 5 June 2018

DOI: 10.1134/S0370274X18130131

Back in 1918, in his research for factors limiting the performance of hot cathode amplifiers, Walter Schottky was the first to understand that discreteness of the elementary charge, e, gives rise to current fluctuations in a vacuum tube [1]. The noise spectral density is determined by $S_I = 2eI$, where I is the tube's average current. Along with the Johnson–Nyquist noise in thermal equilibrium [2], such fluctuations – now called the shot noise – represent one of the two fundamental sources of current noise in a generic conductor. Diluted electron flow in a vacuum tube obeys Poissonian statistics for purely classical reasons [3]. By contrast, in solid-state conductors, the shot noise arises from the random partitioning of a degenerate electron stream owing to scattering off disorder or inhomogeneities [2]. This results in much richer possible outcomes of the shot noise measurement and brings valuable information about charge transport mechanism, making noise an attractive experimental tool in mesoscopic physics.

This article gives a brief overview of our recent research and is mainly intended to illustrate the strength and, perhaps, the beauty of the noise measurements approach. The body of the paper is divided into five sections, which are largely mutually independent.

In section I we investigate the noise in the hopping regime in a quantum Hall (QH) insulator. Without the magnetic field, some of us [4] have observed Poissonian shot noise in variable range hopping regime in a GaAs two-dimensional electron system. Here we extend this work to the QH transport regime in Corbino-disk-shaped devices and observe that at increasing magnetic field the shot noise substantially diminishes. This indicates that the hopping transport tends to order in the QH transport regime, which is qualitatively explained considering the impact of delocalized states on the random hopping network.

Section II is devoted to the shot noise of the edge transport in 2D topological insulators realized in HgTe inverted band quantum wells [5–7]. This work extends previous measurements of some of us performed in the regime of strongly disordered edge conductance [8] and a nearly ballistic regime in lateral p-n junctions [9]. In 14 nm wide quantum wells, hosting high-quality 2D topological insulator [10], we measure the shot noise of the long compared to the mean-free path edge channels. At low enough temperatures we obtain the shot noise close to the expectation for diffusive quasiclassical transport scenario [11]. Along with the temperature dependence of the edge resistance, this enables us to exclude some microscopic models of backscattering in helical edge channels.

Section III addresses the problem of interface quality in diffusive InAs nanowires with contacts made of Al. Here we compare the transport data in the superconducting state in zero magnetic field and the shot noise data in the normal state in a finite magnetic field for two different devices. In one device, the observed increase of the shot noise above the universal value in diffusive conductors is found to correlate with the decrease of the Andreev reflection probability. This is a clear indication of the built-in tunnel barriers. We discuss possible origin of the tunnel barriers and estimate the ratio between the diffusive and tunnel parts of the nanowire resistance.

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In section IV we study shot noise in a Coulomb blockaded single-wall carbon nanotube based quantum dot. We reproduce well-known results of sub-Poissonian shot noise in sequential tunneling regime [12–15], full Poissonian noise of elastic cotunneling [14, 15] and giant super-Poissonian noise [12, 15], which is a result of very fast modulation of the quantum dot current by some switching effect.

Section V gives the estimate of the voltage noise in a resistive state of a superconducting film owing to spontaneous fluctuations of electronic temperature. Here, we provide a straightforward estimate of a purely thermodynamic effect, which is expected to dominate over the equilibrium Johnson–Nyquist noise, the noises caused by quantum phase slips [16] and by the fluctuations of the order parameter [17].

In summary, we discussed several examples how non-equilibrium noise measurements shed light on microscopic aspects of mesoscopic electron transport. Such experiments directly probe electronic correlations, elastic scattering, and energy relaxation in various transport regimes, from normal to superconducting and from ballistic to localized. Hopefully, in this short review, we demonstrated that measuring noise is not only a powerful but also a beautiful approach in experimental condensed matter physics.

We are grateful to Z.D. Kvon, L. Sorba, G. Biasiol, J. Becker and D. Ruhstorfer for help and acknowledge discussions with K.E. Nagaev, T.M. Klapwijk, A.V. Semenov, A.G. Semenov, M.A. Skvotsov, G.E. Fedorov and A.A. Zhukov. The experimental work was partly supported by the Russian Science Foundation Project # 16-42-01050 and theoretical estimation in section V was supported by the Russian Science Foundation Project # 17-72-30036. G.K. acknowledges support from Deutsche Forschungsgemeinschaft Project # KO-4005/5-1.

Full text of the paper is published in JETP Letters journal. DOI: 10.1134/S0021364018130039

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