Do Histograms Constitute a Proof for Conductance Quantization?

In a recent Letter Scheer *et al.* [1] reported measurements of the nonlinear current-voltage characteristics for atom-size point contacts of aluminum in the superconducting state. For a single quantum mode, exact theoretical expressions have been obtained [2] and Scheer *et al.* combined a number of these single mode curves to fit the experimental current-voltage relations. The agreement is impressive and they reach the important conclusion that "more than one channel contributes to the transport, even for contacts with a total conductance lower than G_0," where $G_0 = 2e^2/h$ is the conductance quantum. For a contact of $G_0 \simeq 1$ typically three modes are found.

Apparently, for atom size aluminum contacts we can describe the conductance as being carried by a finite number of fairly well-defined modes, yet we cannot speak of the conductance as being quantized, since this requires that each occupied mode has a transmission probability close to 1, and that the number of these modes is given by the ratio of the conductance to G_0.

Atom size contacts for the simpler monovalent metals Cu, Ag, and Au [3] and Na [4] have been described in terms of quantized conductance. In these cases the interpretation is primarily based on the observation of peaks in histograms of the relative frequency of detection for each conductance value in large series of runs of contact breaking. The noble metals show peaks near (1, 2, 3, and 4)G_0, whereas Na has peaks near (1, 3, 5, and 6)G_0. The latter series of peaks fits exactly the series predicted for the degenerate modes in a cylindrically symmetric contact.

In their Letter Scheer *et al.* [1] raise the question "what makes atomic-size contacts adopt, statistically, configurations with nearly integer values of the conductance?" However, for the metal which they studied, aluminum, no histograms have been reported. One might be inclined to dismiss the lack of true conductance quantization in aluminum by pointing out that it is a trivalent metal, having both s and p electrons. This might also be the reason for the unusual slope of the plateaus between the jumps, where the conductance increases while stretching the contact [5]. Having seen the results of Scheer *et al.* we proceeded to record histograms for Al at 4.2 K, using the mechanically controllable break-junction (MCB) technique [4,5], and the result is shown in Fig. 1. To our surprise, there is a lot of well-resolved structure, with up to four peaks which have a separation of the order of the conductance quantum. Compared to the monovalent metals, the peak near $1G_0$ is rather broad and centered at a lower conductance ($\simeq 0.8G_0$). On the other hand, the peaks near $3G_0$ and $4G_0$ are shifted to *higher* conductances.

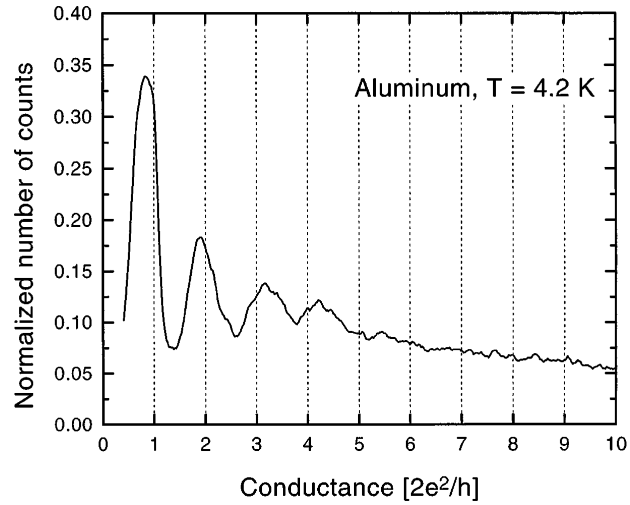

FIG. 1. Histogram constructed from 30 000 individual conductance curves for two different samples of 99.999% purity. Each curve was recorded while stretching the contact to break, using the MCB technique at 4.2 K. The conductance was measured using a dc voltage bias of 10 mV.

In view of the results of Scheer *et al.*, the peaks in Fig. 1 cannot be interpreted as being the result of conductance quantization. The peak at 1 then likely results from the conductance determined by a contact geometry having a single atom bridging the two electrodes. Similarly, the higher peaks could be the result of favorable atomic configurations, although no evidence for such configurations has been reported from molecular dynamics simulations or other theoretical modeling. The new results obtained for aluminum force us to reconsider the value of the histograms as evidence for quantized conductance. Although, in particular, the characteristic series of peaks observed for sodium will be difficult to explain by other models, the role of atomic configurations has to be taken into account in the interpretation of conductance histograms.

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Received 16 June 1997 [S0031-9007(97)04052-0]
PACS numbers: 73.40.Jn, 73.20.Dx, 74.50.+r

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