Correlation energy of conductance fluctuations in ballistic silver point contacts

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We have studied conductance fluctuations of microfabricated silver point contacts, which operate in the ballistic electron-transport regime. The correlation energy E_c of the conductance fluctuations has been determined from the voltage correlation of the fluctuations, and from the temperature and modulation voltage dependence of the fluctuation amplitude. For all the devices investigated $E_c \approx 1$ meV. This value is in good agreement with a model where the conductance fluctuations are due to quantum interference of electrons backscattered by a few impurities at a distance of the order of the elastic mean free path from the constriction. For temperatures higher than E_c/k_B or for ac modulation voltages exceeding E_c/e, a decrease of the fluctuation amplitude is observed, in agreement with averaging over uncorrelated fluctuation patterns. However, for dc bias voltages larger than E_c/e the amplitude of fluctuations of the differential conductance remains unchanged for voltages up to $V \approx 8$ mV. This behavior is in strong contrast to observations and theoretical descriptions of conductance fluctuations in diffusive metallic samples.

I. INTRODUCTION

The discovery of reproducible, sample specific fluctuations in the magnetoconductance of diffusive metallic samples with submicrometer dimensions measured at low temperatures[1] has attracted much attention from both experimentalists and theoreticians. A theoretical description of the fluctuations was given soon after the discovery.[2,3] As expressed in the ergodic hypothesis,[3] the electron interference responsible for the conductance fluctuations can be equivalently altered by changing the impurity configuration, the magnetic field, and/or the energy of the conduction electrons. Conductance fluctuations as a function of electron energy can be observed directly in metal-oxide-semiconductor field-effect transistors[4–6] (MOSFET's), where the Fermi energy of the conduction electrons can be changed by varying the gate voltage. The typical gate-voltage (energy) difference between the peaks and valleys in a conductance versus the gate-voltage (energy) plot is called the correlation voltage (energy). In metals the Fermi energy of the electrons cannot be changed, but a nonequilibrium electron distribution can be created by passing an electric current through the sample. Conductance fluctuations induced by changing the current through the sample have been observed by Webb, Washburn, and Umbach.[7]

The correlation energy plays an important role in the temperature dependence of the fluctuations. When the correlation energy is smaller than the thermal energy range ($\approx k_B T$) of the electrons, this range can be envisioned to consist out of $k_B T/E_c$ independent energy bands contributing to the conductance fluctuations. Classical averaging of the contributions leads to a decrease of the fluctuation amplitude according to $\delta G \propto (E_c/k_B T)^{1/2}$. This dependence, known as energy averaging, has been observed experimentally and values of E_c have been determined.[8,9] Intuitively, the same arguments are expected to apply to the reduction of the fluctuation amplitude by a voltage across the sample. For diffusive mesoscopic samples, which are small enough to ignore inelastic scattering, the energy range of the electrons contributing to the conductance is equal to the voltage across the sample.[10] So, a decrease of the fluctuation amplitude by a factor $(E_c/eV)^{1/2}$ is expected. The voltage dependence of the fluctuation amplitude has been calculated by Larkin and Khmel'nitskii.[10] By using diagrammatic techniques and incorporating the electric potential in the diffusion propagator they arrived at a reduction of the fluctuation amplitude by a factor $(E_c/eV)^{2/3}$. This reduction was confirmed by experiments on diffusive Sb wires and was used to determine E_c.[7]

Conductance fluctuations due to quantum interference have also been observed in quasiballistic and ballistic conductors defined in the two-dimensional electron gas of a $GaAs/Al_xGa_{1-x}As$ heterostructure.[11,12] It is found that the magnetic-field scale of the conductance fluctuations in the quasiballistic regime can be strongly influenced by the effect of flux cancellation acting on specific electron trajectories,[11] while in the ballistic regime the fluctuations occur in special geometries, which can trap electrons for a sufficiently long time to give rise to interference.[12]

Recently, we have observed reproducible, aperiodic magnetoconductance fluctuations in three-dimensional (3D) nanofabricated metallic point contacts, which operate ballistically.[13] In these point contacts electrons pass the constriction between two electrodes without scattering. We call the point contacts 3D to indicate that translational electron motion takes place in *three* directions (no confinement), both in the constriction region as well as in the electrode regions, in contrast to ballistic point contacts defined in the two-dimensional (2D) electron gas of a $GaAs/Al_xGa_{1-x}As$ heterostructure. As explained in Ref. 13 our point-contact geometry cannot give rise to flux cancellation or trapping of electrons. On the contrary, the characteristic field scale B_c of the fluctuations suggest an explanation in terms of quantum interference of electron waves traveling along loops much larger than the constriction area. Good agreement with the observed B_c is found when interference loops with size of the order of the elastic mean free path l_e are considered. This suggests that electrons, backscattered to the constriction by impurities located outside the contact region, typically at a distance l_e from the center of the point contact, are responsible for the magnetoconductance fluctuations.

So far all experiments on the correlation energy of conductance fluctuations were carried out in systems with diffusive electron transport. In this paper we focus on the correlation energy of conductance fluctuations in ballistic silver point contacts. The conductance fluctuations have been measured by sweeping the voltage or the magnetic field. The correlation energy E_c is derived from the dc bias-voltage correlation of the fluctuations and from the fluctuation amplitude as a function of temperature and ac modulation voltage. The dimensions of the interference loops, determined from the correlation energy, are in good agreement with the values found from the characteristic magnetic-field scale. The bias-voltage dependence of the amplitude of magnetoconductance fluctuations in the ballistic point contacts is found to be significantly different from the voltage dependence predicted and/or observed for diffusive systems.[14]

II. FABRICATION AND EXPERIMENTAL TECHNIQUE

We present data on three ballistic silver point contacts. The point contacts are fabricated by evaporating a metal layer of high purity on both sides of a 20-nm-thick silicon nitride membrane, patterned with a nanohole. A schematic cross section is shown in Fig. 1. Patterning is done with electron-beam lithography and reactive ion etching.[15–17] The typical hole diameter $2a$ is 10 nm.

During evaporation the membrane is rotated, so that the hole is filled without breaking the high vacuum. Thus, it is ensured that the contact region has the same purity as the electrodes, which, as deduced from residual resistance measurements, have an elastic mean free path in the range 200–240 nm. The purity of the contact region was confirmed by the high quality of the point-contact spectra measured on the devices. In general, our devices yield point-contact spectra with a very low background and with well-resolved transverse- and longitudinal-acoustic phonon peaks, obeying the scaling of intensity with contact resistance characteristic of a clean orifice.[18] These properties are clear evidence that the point contacts operate in the ballistic regime ($l_e \gg a$). In view of these arguments we expect that the value of l_e of the electrodes is a good measure of the purity of the contact region of the devices.

The point contacts are cooled to low temperatures in a dilution refrigerator. The magnetic field is oriented parallel to the constriction axis. The conductance is always measured differentially [$G(V)=dI/dV$] by applying both a dc bias voltage and an ac modulation voltage. The rms amplitude of the modulation is small $V_{mod} < 0.5$ mV, except when measuring the dependence of the fluctuations on V_{mod}.

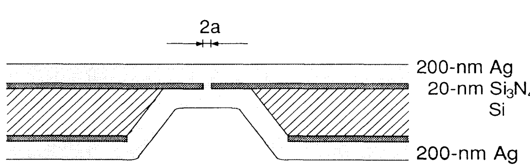

FIG. 1. Schematic cross section of a microfabricated point contact. The diameter $2a$ of the point contacts presented here is in the range 10–16 nm.

III. EXPERIMENTAL RESULTS

The magnetoconductance of a ballistic Ag point contact of $R=5.5\Omega$ is shown in Fig. 2 at different temperatures. The conductance is measured at zero dc bias. The point contact has a contact radius $a=8$ nm and elastic mean free path $l_e=200$ nm. Aperiodic fluctuations, which are reproducible in time, are superimposed on a temperature-independent background. The amplitude of the fluctuations does not change up to $T \approx 5$ K. Above $T \approx 5$ K the amplitude of the conductance fluctuations decreases with increasing temperature.

Conductance fluctuations can also be observed by sweeping the bias voltage applied across the point contact, demonstrating the ergodic property of the fluctuations. For a Ag point contact of $R=6.5\Omega$, the differential conductance has been measured as a function of dc bias voltage at different magnetic fields. Figure 3(a) shows a conductance trace at zero magnetic field. In Fig. 3(a) the conductance fluctuations are obscured by a large

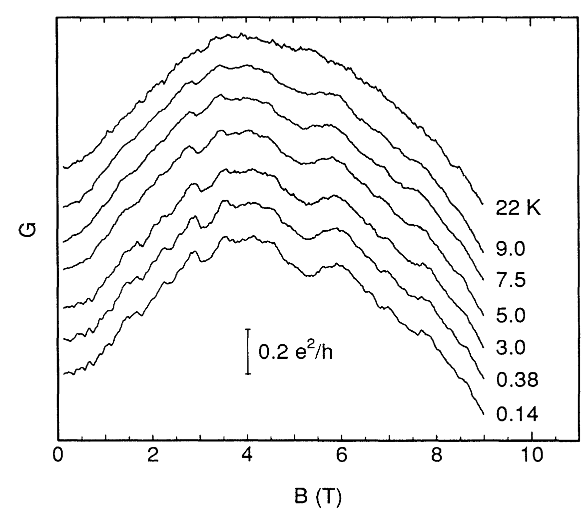

FIG. 2. Magnetoconductance traces of a Ag point contact of $R=5.5\Omega$ at different temperatures. The conductance traces were measured at zero-bias voltage. The curves have been offset for clarity.

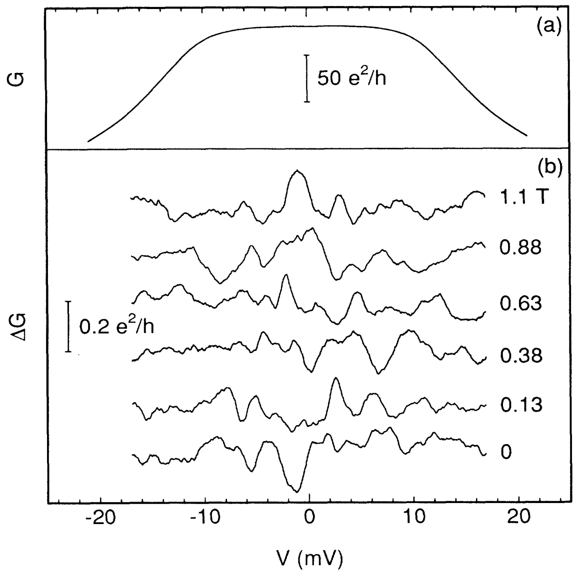

FIG. 3. (a) Differential conductance G of a Ag point contact of $R = 6.5\Omega$ as a function of bias voltage V. (b) Conductance fluctuations ΔG after subtraction of the background, as a function of bias voltage for different magnetic fields. The fluctuation pattern changes with magnetic field. The curves have been offset for clarity.

voltage-dependent background. The conductance decrease observed for $|V| > 10$ mV is due to the increased electron-phonon scattering in this voltage range. Fortunately, the fluctuations can be separated from the overall conductance by a straightforward procedure. Averaging a sufficient number of traces measured at different magnetic fields yields a completely smooth background curve, which is subtracted from the original data to obtain the fluctuations ΔG as a function of bias voltage, shown in Fig. 3(b). The fluctuation amplitude becomes smaller above $|V| \approx 10$ mV due to the already-mentioned electron-phonon scattering. In the voltage range -8 mV $< V < 8$ mV the fluctuation amplitude is $\delta G \approx 0.054 e^2/h$. This value is in good agreement with $\delta G \approx 0.048 e^2/h$ obtained from a magnetoconductance trace of the same point contact at zero-bias voltage. The voltage correlation scale is calculated using the correlation function $F(\Delta V) = \langle \Delta G(V) \Delta G(V + \Delta V) \rangle$, where $\langle\ \rangle$ denotes averaging over voltage. By averaging over 18 correlation functions obtained at different magnetic fields [of which six are calculated from magnetoconductance traces shown in Fig. 3(b)], the half width of the average $F(\Delta V)$ amounts to $V_c \approx 1$ mV.

In Fig. 4(a) the temperature dependence of the rms amplitude δG of magnetoconductance fluctuations of a Ag point contact, for which magnetoconductance traces have already been shown in Fig. 2, in the range $2 < B < 12$ T, is displayed. The fluctuation amplitude is obtained by first subtracting a background curve from the magnetoconductance trace. As can be seen from Fig. 4(a) the amplitude δG is constant at low temperatures and decreases at higher temperatures. The decrease of δG is in good agreement with the expected averaging of independently contributing energy bands, $\delta G \propto T^{-1/2}$. This theoretical dependence, taking a knee temperature $T = 4$ K, is shown in the dashed line. A value $E_c \approx 0.7$ meV is calculated from the temperature T where δG has dropped by a factor $\sqrt{2}$ [denoted by the arrow in Fig. 4(a)].

In Fig. 4(b) the *ac modulation* voltage and the *dc bias-voltage* dependence of δG are shown. Similar to the temperature dependence, δG is constant when the rms modulation voltage V_{mod} is small and then decreases with increasing V_{mod}. Shown in the dashed line is the decay $\delta G \propto V_{\mathrm{mod}}^{-1/2}$ as expected for averaging over V_{mod}/V_c independent energy bands. The value of V_{mod} where δG is reduced by a factor $\sqrt{2}$ gives $E_c \approx 1.1$ meV [denoted by the arrow in Fig. 4(b)]. Also shown in Fig. 4(b) is the *dc bias*-voltage dependence of the amplitude δG of differentially measured magnetoconductance fluctuations. In contrast to the ac modulation dependence, *the fluctuation amplitude does not decrease for voltages $V > V_c$ up to a voltage $V \approx 10$ mV*. For $|V| > 10$ mV, the strongly increased electron-phonon scattering reduces δG.

Another way to determine the correlation energy is to study the voltage correlation of the magnetoconductance traces. This method is preferred over direct studies of the voltage dependence of the conductance, since the background in magnetoconductance measurements is considerably smaller. Exploiting the ergodic property of the fluctuations, a correlation function $F_B(V, V + \Delta V)$ can be obtained, which is given by

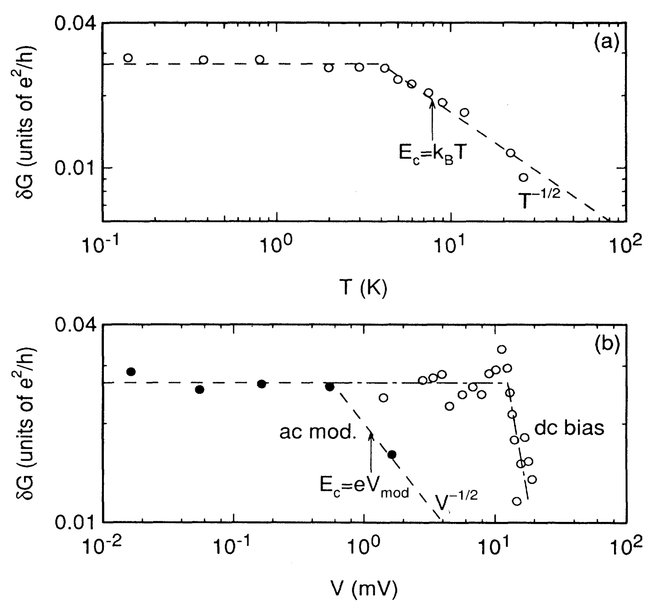

FIG. 4. (a) Temperature dependence of the rms fluctuation amplitude δG of a Ag point contact of $R = 5.5\Omega$, for which magnetoconductance traces are shown in Fig. 1. (b) δG as a function of the rms ac modulation voltage at zero bias (closed circles) and δG as a function of dc bias voltage (open circles). Dashed lines illustrate the $\delta G \propto T^{-1/2}$ and $\delta G \propto V^{-1/2}$ dependence at high temperature and high modulation voltage, respectively. The dash-dotted lines guide the eye.

$$F_B(V,V+\Delta V)=\langle G(V)G(V+\Delta V)\rangle - \langle G(V)\rangle\langle G(V+\Delta V)\rangle \,, \quad (1)$$

where $G(V)$, $G(V+\Delta V)$ are magnetoconductance traces at dc bias voltages V and $V+\Delta V$, and $\langle\ \rangle$ denotes averaging over the magnetic field. A correlation function $C(V,\Delta V)$, normalized with respect to the fluctuation amplitudes of each trace, is given by

$$C(V,\Delta V)=\frac{F_B(V,V+\Delta V)}{\sqrt{F_B(V,V)F_B(V+\Delta V,V+\Delta V)}} \,. \quad (2)$$

The voltage correlation at bias V is defined as $V_c=(V_{c+}+V_{c-})/2$, where the half widths V_{c+},V_{c-} of the correlation function are the solutions of $C(V,V_{c+})=C(V,-V_{c-})=\frac{1}{2}$. Correlation functions for a Ag point contact of $R=11\Omega$ with $a=6$ nm and $l_e=240$ nm, at different bias voltages, obtained using this procedure, are shown in Fig. 5(a). For each function the correlation $C(V,\Delta V)$ of the magnetoconductance traces with the trace at the center voltage V [for which $C(V,0)=1$] decreases with increasing voltage difference ΔV. In Fig. 5(b) the correlation voltage V_c for two Ag point contacts, of $R=5.5\Omega$ and $R=11\Omega$, are plotted as a function of bias voltage. The values of V_c are independent of voltage within experimental accuracy, for $V<8$ mV. The temperature and modulation voltage dependence of the amplitude of the conductance fluctuations for the $R=5.5\Omega$ point contact were already shown in Fig. 4.

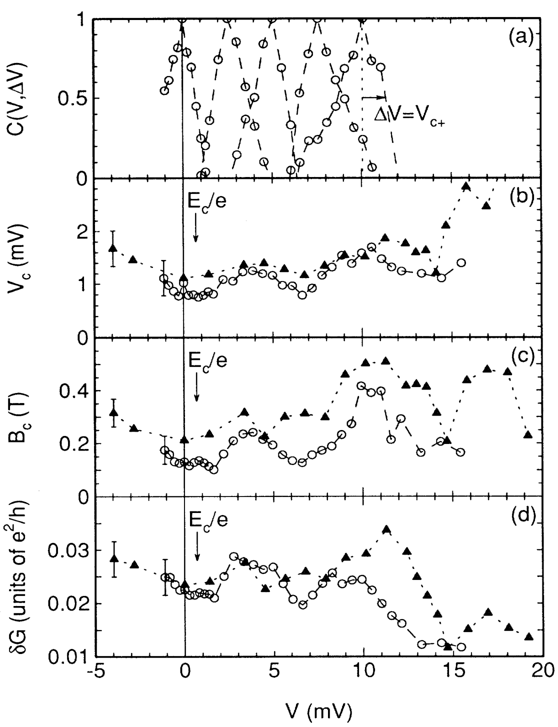

FIG. 5. Bias-voltage dependence of characteristic parameters of conductance fluctuations observed in two Ag point contacts of $R=5.5\Omega$ (closed symbols) and of $R=11\Omega$ (open symbols). (a) Voltage correlation functions $C(V,\Delta V)$ for the $R=11\Omega$ point contact. For the correlation function at $V\approx10$ mV the value for $\Delta V=V_{c+}$ is exemplified. (b) Voltage correlation V_c calculated from the correlation function $C(V,\Delta V)$. (c) Magnetic-field scale B_c and (d) rms fluctuation amplitude δG of magnetoconductance traces. The error bar in each curve in (b)–(d) is representative for all the data points in the curve. The lines connecting the data points serve to guide the eye.

To allow a complete characterization of the conductance fluctuations, the magnetic-field correlation scale B_c and rms fluctuation amplitude δG are given in Figs. 5(c) and 5(d). The variations of V_c, B_c, and δG in the voltage range $V<8$ mV are representative of the accuracy of these parameters [shown by the error bars in Figs. 5(b)–5(d)], which is limited by the finite experimental range of the magnetic field ($B<12$ T). Therefore, V_c, δG, and B_c should be considered as roughly constant in the range $V<8$ mV. The decrease of δG and the increase of B_c above 8 mV clearly exceed the variations at lower voltages and coincide with a reduction of the phase coherence length in this range of voltages due to enhanced electron-phonon scattering [see Fig. 3(a)]. Above ≈12 mV the determination of V_c and B_c rapidly becomes unreliable because of a too small fluctuation amplitude.

The behavior of δG and B_c of the two devices presented in Fig. 5 is consistent with a different characteristic loop size as expected from the difference in the elastic mean free path l_e for the two point contacts. From Fig. 5(c) it can be seen that B_c of the $R=5.5\Omega$ point contact is slightly larger than B_c for the $R=11\Omega$ point contact over the whole voltage range. Using $B_c\approx\Phi_0/l_e^2$ and the observed value $B_c=0.2$ T at zero-bias voltage for the $R=5.5\Omega$ point contact, we obtain $l_e\approx140$ nm, which is smaller than $l_e\approx190$ nm obtained from the observed value $B_c=0.12$ T at zero-bias voltage for the $R=11\Omega$ point contact. This qualitatively agrees with $l_e=200$ nm measured for the electrodes of the $R=5.5\Omega$ point contact and $l_e=240$ nm measured for the electrodes of the $R=11\Omega$ point contact. This agreement between the two sets of l_e values is as good as can be expected for the approximate relationship $B_c\approx\Phi_0/l_e^2$. The decrease of δG for the $R=5.5\Omega$ point contact [Fig. 5(d)] occurs at a higher voltage compared to the $R=11\Omega$ point contact. The voltage dependence of the phase coherence length L_φ is rather similar for point contacts of a given material. Since a decrease of δG is expected when L_φ becomes smaller than the circumference of the loops, the higher voltage at which δG drops is consistent with a smaller characteristic loop size for the $R=5.5\Omega$ point contact.

IV. DISCUSSION

The temperature dependence of the amplitude of the conductance fluctuations in diffusive samples is determined by the correlation energy E_c and the phase coherence length L_φ. In analogy with the exponential decay of the amplitude of Aharonov-Bohm oscillations in loop geometries when L_φ becomes smaller than the loop circumference,[19] the dependence of L_φ on δG in ballistic point contacts is expected to be $\delta G\propto\exp(-nl_e/L_\varphi)$ with

$L_\varphi \propto T^{-p/2}$, where p depends on dimensionality and the inelastic-scattering mechanism. From the linear rather than exponential decrease of $\log(\delta G)$ with $\log(T)$ observed in Fig. 4(a), we conclude that the dependence of L_φ on temperature does not contribute to the observed behavior. However, L_φ might play a role at higher temperatures.

The behavior of δG in Fig. 4(a) is in good agreement with the mechanism of energy averaging, as described in the Introduction for mesoscopic diffusive samples. Below a certain temperature the amplitude is constant and above this temperature the amplitude is reduced by a factor $(E_c/k_BT)^{1/2}$. The value $E_c = k_BT \approx 0.7$ meV from the temperature dependence in Fig. 4(a) is in good agreement with the half width $E_c = eV_c \approx 1$ meV of the average correlation function obtained from the conductance as a function of voltage (Fig. 3), and in good agreement with $E_c = eV_c \approx 1.1$ meV of voltage correlation functions of magnetoconductance traces, as shown in Fig. 5(b). It is also close to the value for the amplitude of the modulation voltage $E_c = eV_{\text{mod}} \approx 1.1$ meV, which leads to a reduction of the fluctuation amplitude with a factor $\sqrt{2}$ [Fig. 3(b)]. At first sight E_c is surprisingly large compared to $E_c \approx 3$ μeV found in diffusive mesoscopic gold rings.[9]

For diffusive systems, the correlation energy of the conductance fluctuations according to the theory of Lee, Stone, and Fukuyama,[20] is given by $E_c = \hbar\pi^2 D/L^2$, where D is the diffusion constant and L the sample length. A simple interpretation of this result was pointed out by Stone and Imry.[21] It is important to realize that the interfering electron waves, responsible for the conductance fluctuations, correspond to electrons traveling along different trajectories with energies in a small range around the Fermi energy. Electron waves traversing the sample at different energies accumulate different phases. When the phase differences become of order 1, the interference will be completely changed and so the interference contribution to the conductance. For conductance fluctuations in ballistic point contacts, no complete theory is available yet. As mentioned in the Introduction, the characteristic magnetic-field scale B_c points to interference loops that enclose an area much larger than the constriction. In fact, the value of B_c suggest that the interference loops correspond to electrons that are backscattered to the constriction by only a few impurities located at typically a distance l_e from the center of the point contact. For these loops the correlation energy is given by $E_c \approx \hbar v_F/nl_e$, where nl_e is the circumference of a loop. The value $E_c \approx 0.7$ meV for the Ag point contact of $R = 5.5\Omega$ corresponds to $nl_e \approx 800$ nm or $n \approx 4$, a reasonable value for backscattering loops determined by a few elastic-scattering events. The values of the circumference of the interference loops derived from E_c are in good agreement with the values derived from the magnetic-field scale $B_c \approx \Phi_0/l_e^2$, since $B_c = 0.2$ T for the same Ag point contact gives $l_e \approx 140$ nm. The much smaller value for the correlation energy in the diffusive regime found in Ref. 8 is due to the fact that in the diffusive regime E_c is determined by the sample length and the diffusion constant. The sample length is comparable to nl_e, while D is much smaller for the metal films used in Ref. 8.

The reduction of the fluctuation amplitude by the modulation voltage can be understood in the same way as the temperature dependence. When the modulation amplitude exceeds E_c/e the measured conductance fluctuations will be the classical average of E_c/eV_{mod} independently contributing energy bands.

So far, the temperature and voltage dependence of the conductance fluctuations measured in ballistic point contacts is similar to what is observed in diffusive systems, provided one takes into account that the effective length scale is given by the elastic length l_e. However, it is very remarkable that the fluctuation amplitude and the voltage correlation scale are not changed by a bias voltage exceeding E_c/e [denoted by the arrows in Figs. 5(b) and 5(d)]. A reduction of δG and an increase of V_c are observed by Webb *et al.*[7,22,23] in diffusive systems and are predicted by Larkin and Khmel'nitskii.[10] At first sight, one might expect the same behavior in the ballistic point contacts, since electrons in the energy range determined by the applied voltage contribute to the conductance. First of all, we mention that the theory of Larkin and Khmel'nitskii does not apply since the assumed boundary conditions are not correct for electron transport in ballistic point contacts. For example, Larkin and Khmel'nitskii predict a correlation energy $E_c \approx \hbar v_F/2a$, where a is the constriction radius, whereas our experiments point to $E_c \approx \hbar v_F/nl_e$. Further, Larkin and Khmel'nitskii assume ideal leads, while our interpretation of quantum interference in ballistic point contacts demonstrates the importance of backscattering paths in the leads. An important difference between a ballistic point contact and a diffusive sample concerns the length scale over which the voltage drops. As illustrated in Fig. 6 an applied voltage drops across the whole length of a diffusive sample, while a voltage across a ballistic point contact drops over the constriction region only. In the diffusive regime the electrons feel the electric field everywhere in the sample. In a ballistic point contact the electric field acts only on the electrons when they pass the constriction region. In the diffusive regime increasing the voltage implies not only that more electrons contribute to the current but also that the potential energy of *all* electrons is changed. Consequently, the change in the interference correction to the conductance is due to a change of the interference contributions of *all* conduction electrons. For a ballistic point contact the interference correction to the conduction is due to electrons that are backscattered to the constriction by a few impurities at a distance l_e from the contact region. Along their backscatter trajectories the electrons move in the electrode regions, where the electrical field is virtually zero. So the potential energy of these electrons is not changed when the voltage across the contact is changed. Of course, electrons with higher kinetic energy will be added to the conduction process when the voltage is increased. The interference correction after changing the voltage will be the "sum" of the "old" interference correction and the

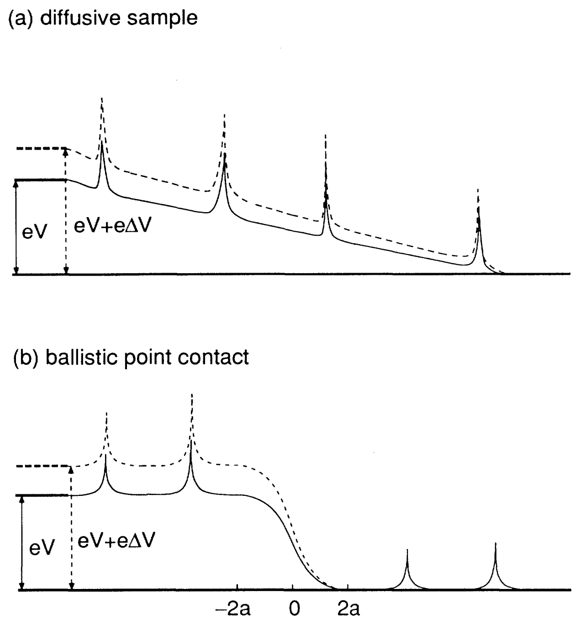

FIG. 6. Illustration of the influence of an applied voltage V and $V+\Delta V$ on the potential energy of the electrons in the presence of impurities (represented by the peaks) for a diffusive sample (a), and for a ballistic point contact (b).

contribution of the added or removed electrons. Since the conductance is measured with a small ac voltage superimposed on a dc bias voltage, only the interference contribution of the added or removed electrons is measured. This contribution is not reduced by scrambling of the different interference contributions of electrons with kinetic energy smaller than the bias voltage minus the modulation voltage. As mentioned above, at present no theory is available yet to describe all aspects of conductance fluctuations in metallic point contacts. The fact that only a few impurities are involved in the electron interference makes the point contact an attractive system to study without having to invoke diagrammatic techniques or random-matrix theory.[24]

V. CONCLUSIONS

In conclusion, we have studied the correlation energy E_c of conductance fluctuations in ballistic silver point contacts. E_c has been obtained from the voltage correlation of the fluctuations and from the temperature dependence and modulation voltage dependence of the fluctuation amplitude. For all three point contacts and for all different types of measurements to determine E_c, we find $E_c \approx 1$ meV. This value is consistent with the model that the fluctuations originate from quantum interference of electrons, which are backscattered from impurities situated at a distance of the elastic mean free path from the constriction. For ac modulation voltages larger than E_c/e or temperatures higher than E_c/k_B, the amplitude of the conductance fluctuations decreases due to averaging over uncorrelated fluctuation patterns. This behavior is very similar to the decrease of the fluctuation amplitude observed in mesoscopic diffusive samples. However, the amplitude of the fluctuations of the differentially measured conductance as a function of dc bias voltage does not decrease for bias voltages larger than E_c/e. This is in strong contrast to experiments and theoretical predictions for conductance fluctuations in diffusive samples.

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[23]We note that Webb *et al.* obtain δG and V_c at a bias voltage V by calculating these parameters from conductance traces as a function of voltage in a small voltage interval around V, while we obtain δG from magnetoconductance traces at voltages in a range around V. However, this is not an important difference since in both cases different realizations of the differential conductance are being measured, yielding an equally justified ensemble average.

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