Phase Persistence in Fano and Aharonov-Bohm Effects

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Fano effect has been studied in a conductance to get phase information of the wave-function in a quantum dot situated in an Aharonov-Bohm (AB) ring [1]. In this work, we show the presence of a series of Fano peaks with similar asymmetry parameter q and without any change in the phase of the AB oscillation for realistic rings in which the current is carried by several channels. The results explain the experiments although qualitatively.

We use a model of an AB ring with a quantum dot in one arm and a control gate in the other, as shown in Fig. 1. Ideal leads with a uniform cross section are continuously connected to the left and right entrances of the AB ring. Three traveling channels carry the current in the arms and leads. Conductance is calculated by multi-channel Landauer's formula from numerically calculated transmission and reflection probabilities with the use of a recursive Green's function technique.

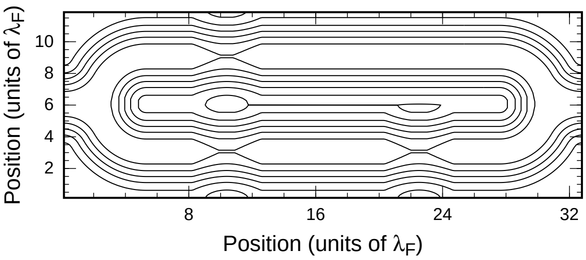
Figure 2 shows an example of the conductance as a function of the control gate in the presence of magnetic flux corresponding to the peak and the dip of the conductance away from the peak region (AB oscillation). Many resonance peaks appear in the conductance and they all exhibit Fano-type interference effects. Among these peaks, those denoted by arrows in the figure are broad but most are quite narrow. The broad resonances correspond to levels in the dot strongly coupled to the main traveling channel in the arm. Both the asymmetry parameter q of the Fano interference and the AB oscillation almost always change their signature at broad peaks. This can easily be understood because the phase of the coupling between these dot levels and those in the arm changes at the resonances.

As is clearly seen in a blow-up of the small-gate-potential region shown in Fig. 3, on the other hand, the crossing of narrow peaks does not change the phase of the AB oscillation. This is because the corresponding levels in the dot do not contribute to the the conductance except in the extreme vicinity of the resonance and the conductance under off-resonant conditions is determined mainly by coupling to levels responsible for broad resonances. Further, the asymmetry parameter q of many narrow Fano peaks present around a broad peak remains similar as is more clear in Fig. 4 in the presence of a weak randomness in the dot.

In actual systems, the conductance exhibits a Coulomb oscillation due to charging energy in the dot excluded in the present calculation. Most of Coulomb peaks are likely to correspond to narrow resonances because of their dominance in the number and therefore both the AB oscillation and the Fano parameter q are expected to remain unchanged at the Coulomb peaks, explaining the essential feature of the experimental results [1].

References

[1] K. Kobayashi, H. Aikawa, S. Katsumoto, and Y. Iye, Phys. Rev. Lett. **88**, 256806 (2002).



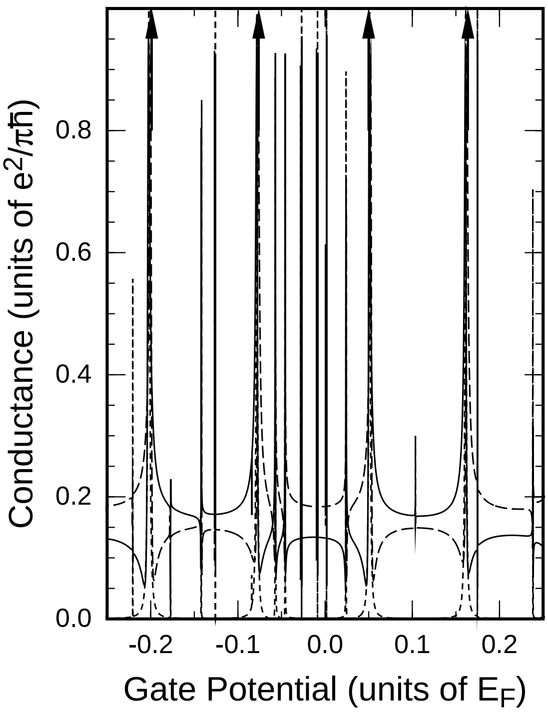
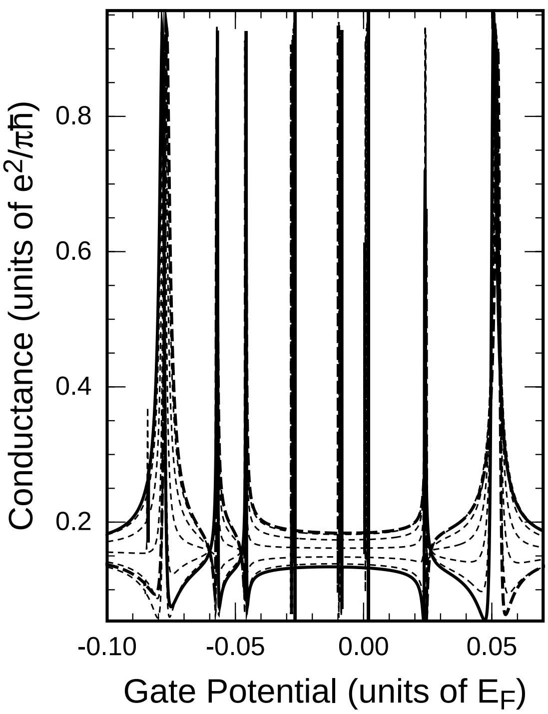


Fig. 1 **Fig. 2**

Fig. 1 Equi-potential lines of the model. λ_F is the Fermi wave length.
Fig. 2 Calculated conductance as the function of gate potential measured in units of the Fermi energy E_F. The Solid and dashed lines correspond to maximum and minimum of the AB oscillation (the magnetic flux passing through the AB ring is different by a half of the flux quantum). The dotted line shows the resonant peaks, when the control gate is pinched off.



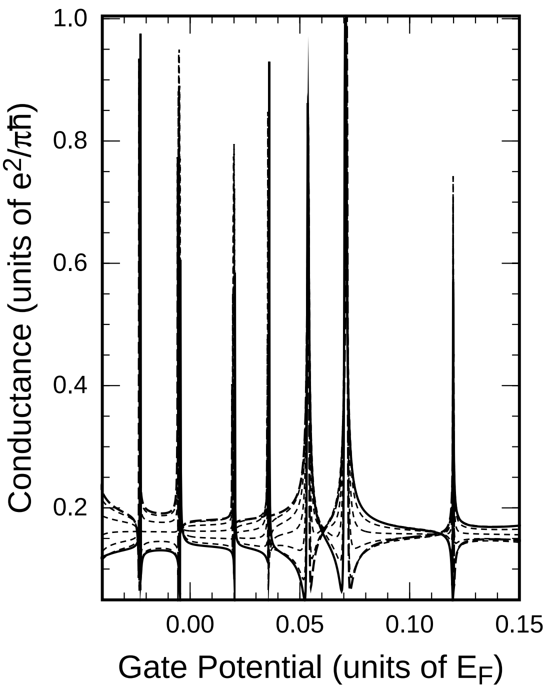


Fig. 3 **Fig. 4**

Fig. 3 Close up view of Fig. 2 between two wide peaks. The magnetic flux is shifted finely at regular intervals.
Fig. 4 Calculated conductance with weak impurities in the quantum dot.