Kondo-like Behaviour as Manifestation of Many-body Interactions around a Quantum Antidot

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We have observed Kondo-like behaviour of the tunnelling conductance through a quantum antidot in the quantum Hall regime [1]. When the two spins of the lowest Landau level form bound states around an antidot, the tunnelling current between the source and drain current-carrying edge states via the antidot shows a zero-bias anomaly in source-drain bias measurements at low temperatures (Fig. 1). The amplitude of the anomaly becomes larger as the coupling between the extended edge states and the antidot states becomes stronger. Under a small source-drain bias (~ 10 μV), the extra resonances in the region of the anomaly become totally suppressed (Fig. 2). The zero-bias anomaly is absent at a higher temperature (~ 190 mK) (Fig. 3), and the antidot conductance shows so-called double-frequency Aharonov-Bohm oscillations [2].

This behaviour closely resembles that of the Kondo effect in quantum dots [3], implying the presence of a localised electron with an unpaired spin around the antidot, causing a Kondo-like correlated tunnelling. However, certain features in the experimental results invalidate such a simple model. The most important of all is the absence of spin splitting. As the system is in a finite magnetic field (~ 1.2 T), the bare Zeeman splitting E_Z (~ 30 μeV at 1.2 T in GaAs) should split the zero-bias anomaly by ~ 60 μV [3]. However, our zero-bias anomaly does not show such a splitting, indicating that the "spins" are degenerate within $E_Z/3$. Another important issue is that the amplitude of the resonances seems to saturate at e^2/h. This should not be the case if the two spins are involved in the resonances, as the amplitude can be as large as $2e^2/h$.

The transport measurements of quantum antidots give a useful insight into the structure of quantum Hall edge states. For example, we have shown [2] that double-frequency Aharonov-Bohm oscillations at high magnetic fields (> 3 T) can arise from the compressibility of the quantum Hall liquid [4]. If two concentric compressible rings (in the regions where the local filling factor is $0 < \nu < 1$ and $1 < \nu < 2$) are present around the antidot, the resonance through the outer compressible region (belonging to, say, the spin-down Landau level) is expected to occur twice per h/e period, due to the screening of the charging effect [5] as the magnetic field is varied. In the low-field region where the zero-bias anomaly is observed, the double-frequency oscillations at high temperatures (Fig. 3) imply the existence of compressible regions around the antidot. However, it is not well understood whether the self-consistent model should survive at such small magnetic fields where the $\nu = 1$ incompressible region is expected to be weak.

The presence of the Kondo-like behaviour indicates that complicated many-body interactions exist around the edge of the antidot. It is an interesting problem to consider how a Kondo effect can occur in such a system, which cannot be described by the Anderson model. In bulk or at the edge of quantum dots, various spin-related interactions, such as skyrmions [6], are expected. It is very likely that exchange interactions also cause the electronic spins around the antidot not to be ordered. It may be that such a spin texture coupled to the extended edge states gives rise to the zero-bias anomaly, although it is not clear how such interactions lead to the degeneracy required for the Kondo effect.

References

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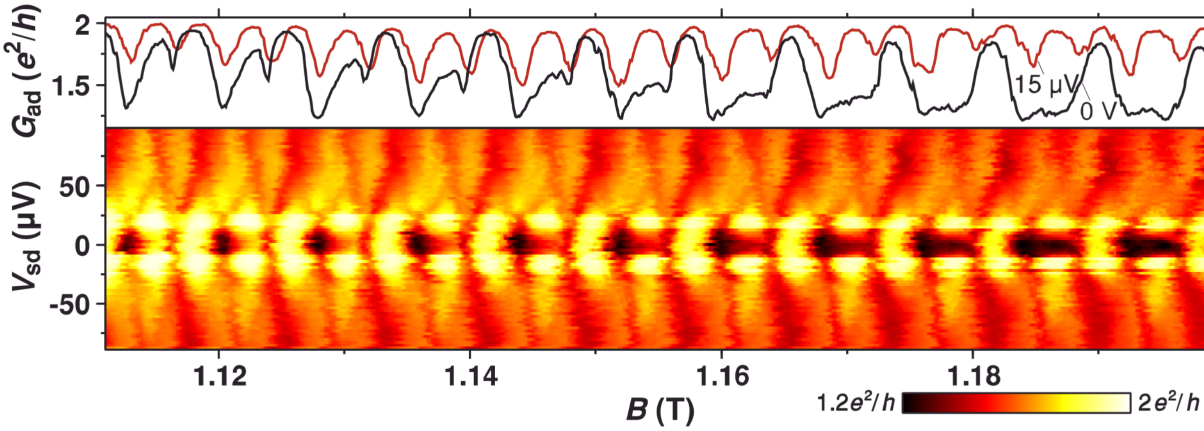

Figure 1. Antidot conductance (G_{ad}) under source-drain bias V_{sd}. Note that a resonance appears as a dip in G_{ad}. Two curves at V_{sd} = 0 (black) and 15 μV (red) are shown in the top panel.

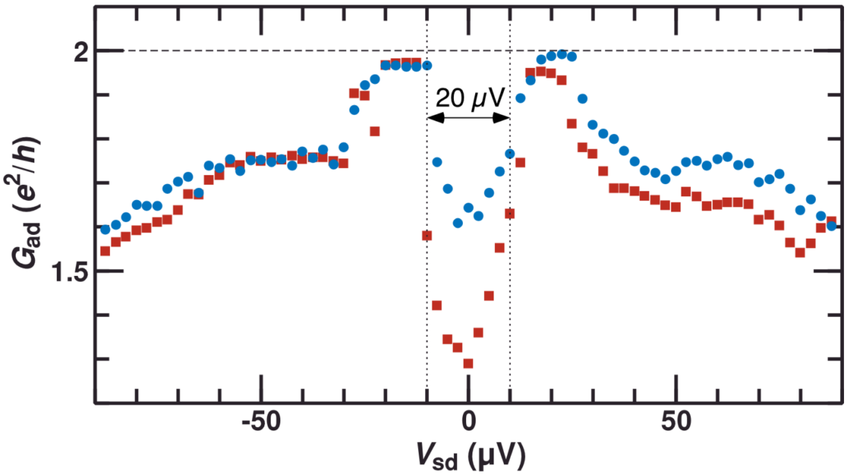

Figure 2. G_{ad} as a function of V_{sd} at B = 1.131 T (blue circles) and 1.178 T (red squares) for the same data as shown in Fig. 1.

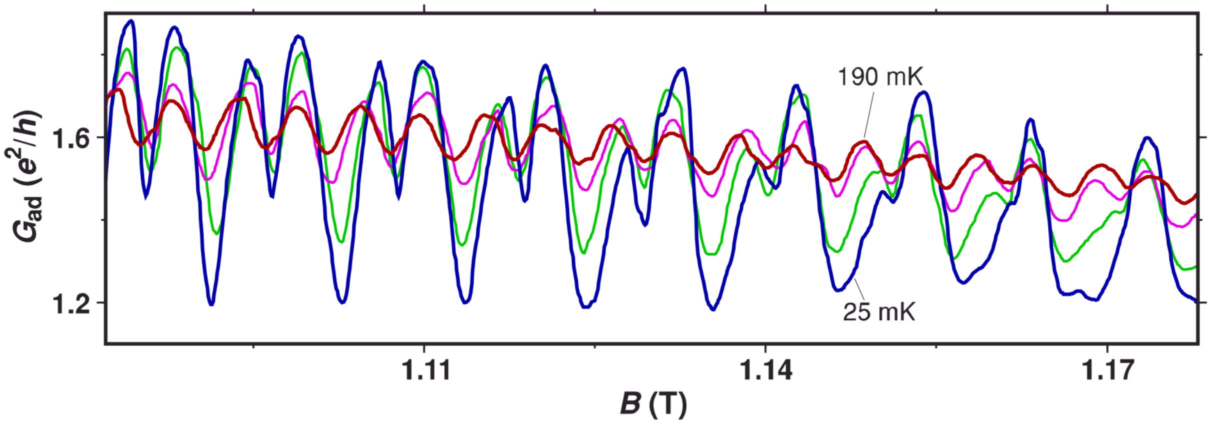

Figure 3. Temperature dependence of G_{ad}.