The increasing sensitivity of the system to environmental decoherence can be used to support the macroscopic character of the quantum state. However, to be even more faithful to Schrödinger's paradigm, one needs to generate two macroscopic states that can be classically discriminated. This condition can be translated into the single-shot state distinguishability using detectors with no microscopic resolution. This is fulfilled for the implemented micro–macro states[1,2], albeit with some intrinsic error probability in distinguishing between the two states. Whereas the discrimination efficiency is predicted to be 90% (ref. 2), due to technical imperfections Lvovsky *et al.* achieved a discrimination efficiency of about 68%.

The two experiments will offer new perspectives and will certainly inspire the design of other physical platforms for similar studies. A relevant challenge is to conceive a viable method for the direct measurement of micro–macro entanglement without displacing the macroscopic quantum state back to the single-photon level. Other intriguing directions may involve the coupling of optical fields to atomic or mechanical systems through resonant reflection or radiation pressure mechanisms to transfer the superposition of the optical fields to a superposition of massive objects. Finally, one could apply the displacement operations on both subsystems to obtain a macro–macro entanglement. ❒

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Published online: 21 July 2013

QUANTUM POINT CONTACTS

Double or nothing?

The role that quasi-bound spins play in the '0.7 anomaly' is controversial. One study suggests that two or more quasi-bound spins may be involved; another advocates that the 0.7 anomaly is a density-of-states effect, needing neither a quasi-bound spin nor spontaneous spin polarization.

Adam Micolich

I am sometimes approached by undergraduate students bemoaning their first 'modern' physics course: "It's so 1940s, how are one-dimensional potential-well problems still relevant today?" My answer is the quantum point contact (QPC) — a beautiful example of the one-dimensional quantum oscillator in a modern context, and a nanoscale electronic device that is still subject to active research.

The QPC is a short, narrow, 1D aperture separating two 2D electron reservoirs in an AlGaAs/GaAs heterostructure (Fig. 1a). The QPC is usually defined electrostatically; its width controlled by the voltage applied to nanoscale 'gate' electrodes. The classic signature of the QPC is a step-like plot of the electrical conductance versus gate voltage, with plateaux at integer multiples of $2e^2/h$ (e is electron charge, h is Planck's constant). These plateaux are easily explained, but the origin of the anomalous plateau[1,2] that is consistently observed at $0.7\times2e^2/h$ is still an enigma.

Two recent papers in *Nature* offer new insight into this 0.7 anomaly. Florian Bauer and colleagues present a 1D model where an interaction-modified 1D density-of-states (DOS) produces the 0.7 anomaly without needing spin-polarization or quasi-bound states[3]. Muhammad Javaid Iqbal and co-workers show interesting new data linking the 0.7 anomaly to one or more spontaneously localized states (SLSs) formed along the QPC[4].

At its simplest, the QPC is a saddle-point potential hosting discrete levels E_n called '1D subbands' (Fig. 1b). More negative gate voltage acts at the centre of the QPC to raise the barrier along x and narrow the well along y, driving the 1D subbands upwards in energy. Conduction in each 1D subband ceases as it crosses the Fermi energy of the adjacent 2D reservoirs. The 1D DOS is proportional to $(E-E_n)^{-1/2}$, fortuitously cancelling the electron velocity, which depends on $E^{1/2}$. This gives the conductance steps their clean shape and equal height.

Bauer *et al.*[3] use a 1D tight-binding model to show that the barrier at the QPC centre and electron–electron interactions combine to modify the 1D local DOS (LDOS) at the centre of the QPC. The saddle-point barrier slows the traversing electrons considerably, with two effects. First, it converts the $(E-E_1)^{-1/2}$ form of the 1D DOS into a ridge-like feature (Fig. 1c) — which Bauer *et al.* call the 'Hove ridge' — giving maximal LDOS above, rather than at, E_1. Second, it strongly enhances electron–electron interactions at the QPC centre, as proposed in ref. 5. The interactions and LDOS act somewhat iteratively: interactions are enhanced where the LDOS is high, which further modifies the LDOS (particularly near the Hove ridge). The net result is a strong modification of the conductance step between 0.5 and $0.9\times2e^2/h$. Screening limits this interaction effect to only the lowest 1D subband at the QPC centre[5]. Most of the experimentally observed behaviours of the 0.7 anomaly are reproduced by the 1D model developed by Bauer and colleagues[3].

Another proposed origin for the 0.7 anomaly is Kondo physics[6]. The parallels between the 0.7 anomaly in QPCs and the quantum-dot Kondo effect were first highlighted by Cronenwett and colleagues[7], who focused on an anomalous peak in the differential conductance versus the d.c. source-drain bias voltage, known as the zero-bias anomaly (ZBA). A key contention with a Kondo scenario is that a QPC is open, and should thus not support a closed, dot-like state[2].

It has since been shown using spin-density functional theory that Friedel oscillations may generate a single quasi-bound spin at the QPC centre[8] (Fig. 1d). The observation of Fano resonances in devices that feature pairs of nearby QPCs suggests that such quasi-bound states may occur experimentally[9].

Iqbal *et al.*[4] provide evidence that links the 0.7 anomaly to quasi-bound-state formation. Their QPC contains six gates, enabling continuous tuning of QPC length. As the length is increased, the 0.7 anomaly rises to merge with the $2e^2/h$ plateau, then re-emerges at $0.7{\times}2e^2/h$; a process repeated periodically three times as the QPC is lengthened from 180 to 610 nm. There is a strong correlation between the periodic modulation and whether the ZBA is a single-, double- or triple-peaked structure, an observation that is attributed to an increasing number of SLSs in the QPC with increasing length (Fig. 1d).

These two new results may fit together well, despite initial apparent differences. A long-favoured alternative to the Kondo scenario is a spontaneous static spin-polarization generated by exchange effects, as proposed in ref. 1. These two schemes are generally considered incompatible, with debate focused on spin-polarization versus Kondo[2]. Bauer *et al.* offer a solution to this impasse; their 0.7 anomaly arises without quasi-bound states or spontaneous spin-polarization — they set the magnetization to be strictly zero at zero magnetic field. The ideas in Iqbal *et al.* may still be compatible with Bauer *et al.*, perhaps as a higher order effect that adds nuance to the 0.7 anomaly and ZBA. This may explain the wide variability in reported ZBA behaviour, another common argument against the Kondo scenario[2].

Some future challenges are whether the $0.25{\times}2e^2/h$ plateau at high source-drain bias voltage[10] — which strongly supports the static spin-polarization scenario— can be explained by Bauer *et al.*, and whether the SLSs suggested by Iqbal *et al.* can be confirmed (using advanced scanning probe techniques, for instance). This quest to understand the fundamental physics of interacting electrons is a great example that the 'modern physics' students learn certainly still has a modern edge. ❒

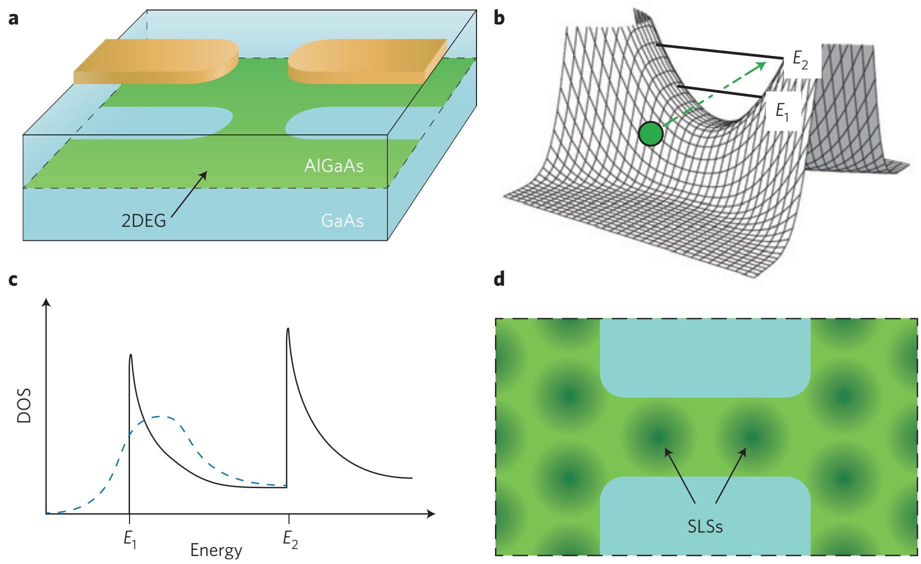

Figure 1 | Two mechanisms for the 0.7 anomaly. **a**, Two negatively biased gates (gold) electrostatically deplete the 2D electron gas (2DEG) at the AlGaAs/GaAs interface (green) to produce a QPC. **b**, The QPC forms a saddle-point potential with discrete energy levels E_n. Incident electrons slow on passing the barrier, locally strengthening electron–electron interactions. **c**, Bauer *et al.* suggest that this modifies the 1D DOS, resulting in a ridge-like feature with maximum slightly above E_1 (dashed blue line). **d**, The 2DEG density has fluctuations at the scale of the Fermi wavelength, called Friedel oscillations. Iqbal *et al.* suggest that these oscillations produce SLSs in the QPC. The number of SLSs increases with QPC length, giving a periodic modulation in the conductance of the 0.7 anomaly.

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FREE-ELECTRON LASERS

Twisted light from an electron beam

A relativistic electron beam travelling on an undulating path interacts with a laser and emits light carrying orbital angular momentum. The wavelengths of these bright twisted-light beams can go down to those of hard X-rays.

Marie-Emmanuelle Couprie

The recent interest in orbital angular momentum (OAM)[1] light beams — which have a cork-screw-like phase distribution and annular intensity — is partly motivated by applications such as particle manipulation[2], channel multiplexing in telecommunications[3] or microscopy[4]. In general, this phase structure is realized by the optical modification of the wavefront. Now, writing in *Nature Physics*, Erik Hemsing and colleagues report the experimental demonstration of an earlier proposal[5] for the generation of OAM light from an electron beam imprinted with a twist profile[6]. The experiment was carried out at the SLAC Next Linear Collider Test Accelerator facility.

More than half a century after the discovery of the laser, tunable X-ray lasers with femtosecond pulse-duration and millijoule energy are the next breakthrough in probing matter with light. The first free-electron laser (FEL)[7] was reported in 1977, and now several FEL facilities exist worldwide. Electrons travel through a