Light on twenty-year-old electron mystery

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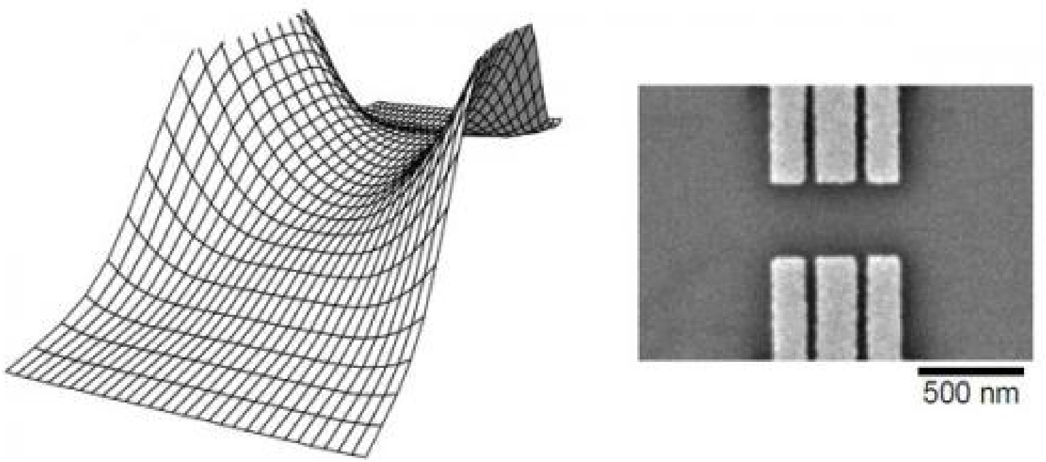

Left: Electrons moving through a short, narrow nano wire experience this as a trip through a mountain pass. Right: Electron microscope image of the device with an adjustable nano wire. Electrons move from left to right under the surface of a semiconductor (dark). The precise shape of the nano channel can be set by applying an electrical voltage to the electrodes on the surface.

Groningen scientists have found an explanation for a mystery that has been puzzling the physics community since 1995. In the scientific journal *Nature* on Thursday 28 August (Advance Online Publication), they explain why electrons pass through very tiny wires (known as quantum point contacts) less smoothly than expected. The observations of the group led by Prof. C.H. van der Wal of the Zernike Institute for Advanced Materials of the University of Groningen will affect electronics on a nanoscale: "Our thinking about this has been too naïve so far."

The mystery concerns nano wires that are about a hundred atoms wide. As early as 1988, the Dutch physicist Bart van Wees, currently a professor at the Zernike Institute, discovered a remarkable effect in this kind of wire. When he made them wider, the flow did not increase gradually but in a stepwise manner. Van der Wal: 'This could be explained by quantum effects that occurred in the wires. There is a formula that describes precisely how these steps occur.'

Unexpected peak

However, in the first step, with the thinnest wires, a tiny exception in the gradual increase was consistently found. 'You see an unexpected peak, after which the conduction increases less quickly than expected for a while. This was already noted in the first publication about this by Van Wees, but initially researchers thought the inconsistency was due to tiny defects in the material used.' In 1995 it was shown that this was not so. 'The peak was real, which meant that physical processes were occurring that we did not properly understand.' Hundreds of publications have appeared about the phenomenon, known as 'Zero Bias Anomaly' (ZBA), but no-one could work out what was causing it.

A few years ago, one of Van der Wal's PhD students made a number of this type of quantum wire. 'They were intended for a completely different type of research. However, we observed the peak and some other interesting trends.' Van der Wal decided to set up a separate research project.

Mountain pass

A Pakistani PhD student, Javaid Iqbal, created a large number of this type of quantum wire. In addition to the 'ordinary' wires whose width is adaptable, he also made wires whose length could be varied. The wires, notably, are very different from the classic electrical wires from our daily lives (a conducting core surrounded by insulating material), but consist of a semiconductor on which electrodes control the edge of a tiny channel. The electrodes create a 'saddle point potential', a sort of a tiny mountain pass where the electrodes on either side control steep walls.

Van der Wal: 'We saw the peak that everyone else was finding. But when we increased the voltage across the wire, suddenly there was a double peak. Others had also observed this, but they thought it indicated that their wire was no longer functioning properly.' By working under extremely controlled circumstances, a fraction above absolute zero temperature, using extremely pure material and by testing a large number of wires, Van der Wal's group has been able to prove that the phenomenon is real. 'And we discovered that the appearance of the ZBA was not only dependent on the voltage, but also on the length of the wire.'

Many body physics

Van der Wal contacted theoretical physicists who had been working on the ZBA for years, particularly a group in Israel who had predicted the existence of a double peak. 'But they had not predicted that it also depended on length.' Together with colleagues from Germany and Spain, they have found an explanation for the phenomenon. 'We now think that electrons get trapped on top of the "mountain pass" that forms the quantum wire,' explains Van der Wal.

Electrons that flow through the wire behave like quantum waves. 'They bash against the walls, and sometimes reflect from the flanks of the mountain pass. They also sense each other's presence.' This results in a complex interaction of various physical phenomena. 'We call this "many body physics". It is very complex. You cannot describe how all the interactions proceed with a single, simple formula.' However, the final result is that an electron is trapped on top of the mountain pass or, in the words of the physicists, becomes localized. This influences the conductivity of the wires and results in the strange peaks. 'And with longer wires two or more electrons can become localized, which results in double or even triple peaks.'

More complex

'What we now know is that the behaviour of electrons in this type of quantum wire is much more complex than we had thought. That has all kinds of consequences.' The characteristics of electrons that pass through such a wire, for example their spin (the precessional motion of electrons), can change in the wire. 'That's something you have to take into account.' The quantum wires are often used in research, for example when making Quantum Dots (used as bits when building a quantum computer).

As well as the article by Van der Wal and his colleagues, *Nature* will be publishing another article on ZBA on Thursday, with many of the same conclusions. 'The mystery is thus as good as solved. The last details will result in interesting discussions, though', remarks Van der Wal enthusiastically.

More information: Iqbal, M. et al. Odd and even Kondo effects from emergent localization in quantum point contacts, *Nature*. DOI: 10.1038/nature12491

Provided by University of Groningen

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