Controllable double quantum dots and Klein tunneling in nanotubes

May 14 2009

Researchers from the Kavli Institute of NanoScience in Delft are the first to have successfully captured a single electron in a highly tunable carbon nanotube double quantum dot. This was made possible by a new approach for producing ultraclean nanotubes. Moreover, the team of researchers, under the leadership of Spinoza winner Leo Kouwenhoven, discovered a new sort of tunneling as a result of which electrons can fly straight through obstacles. The results of the research were published by *Nature Nanotechnology* on April 5, 2009.

A quantum dot can be viewed as a small 'box' which traps a controllable number of electrons. This box is coupled to one or more gate electrodes with which the number of electrons on the dot can be varied. The researchers developed a new technology to make extremely clean nanotube quantum dots. This makes it possible to capture a single electron in a nanotube. Moreover, the researchers succeeded in making the first highly-controllable single electron double dot.

Controlling quantum dots

One of the pipe dreams within quantum mechanics is the construction of a super-powerful quantum computer. In order to do this, it must be possible to manipulate the electron spin of the quantum dots. That would enable quantum information to be stored and read again. However, up until now it has proved impossible to accurately control double quantum dots in nanotubes (two quantum dots linked together) that capture only a single electron.

The researchers used silicon electrodes positioned close to the ultraclean nanotube to accurately control the number of electrons of the quantum dot. Three electrodes were used in the research, although more electrodes can be incorporated. The ultraclean tube ensures that no disruption occurs in the manipulation of the electrons.

Tunnelling

Whilst studying the double quantum dot, the researchers discovered a new type of tunnelling that is analogous to tunnelling according to the Klein paradox. Tunnelling is an effect in which rapidly moving electrons can fly straight through obstacles. The particle goes straight through a barrier even though it does not have enough energy to go over the barrier. Normally tunnelling ceases as soon as the barrier is too large. The famous Klein paradox predicts that if the barrier is made even bigger still, tunnelling can once again take place due to the influence of relativistic quantum mechanics.

In the case of normal tunnelling, electrons can only move from one quantum dot to another due to the tunnel coupling of the wave functions on both sides of the energy barrier within the double quantum dot. Researchers used the silicon gate electrodes to manipulate the barrier and observed tunnelling could become enhanced even though the barrier was increasing, as predicted in the Klein paradox. This method of tunnelling emphasises the close relationship between the physics of semiconductors, such as those in this research, and high-energy physics.

More information: Tunable few-electrodes double quantum dots and Klein tunnelling in ultra-clean carbon nanotubes. *Nature* Nanotechnology G.A. Steele, G. Götz and L.P. Kouwenhoven

Source: Netherlands Organization for Scientific Research