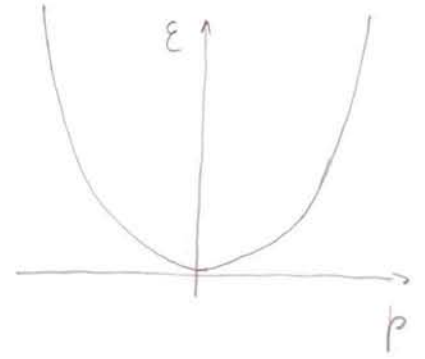


Nanomateriali: nekaj primerov

Enačba gibanja $F = m \frac{dv}{dt}$

kinetična energija $E = \frac{1}{2} m v^2$

gibalna količina $p = m v$; $E = \frac{p^2}{2m}$

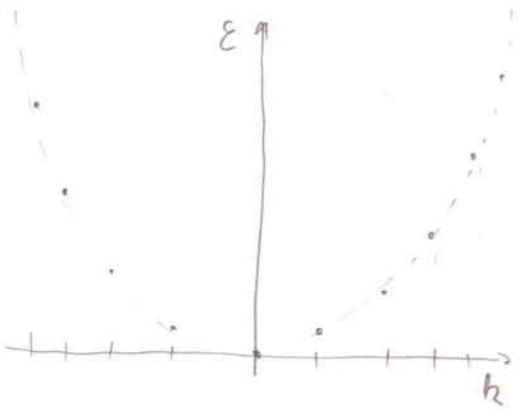


Kvantna mehanika

Enačba gibanja: $[-\frac{\hbar^2}{2m} \frac{\partial^2}{\partial x^2} + V(x)]\psi = E\psi$

Prost elektron $-\frac{\hbar^2}{2m} \frac{\partial^2 \psi}{\partial x^2} = E\psi$; $\psi = A e^{i k x}$; $\frac{\hbar^2 k^2}{2m} = E$ $p = \hbar k$

k - valovna število (vektor)



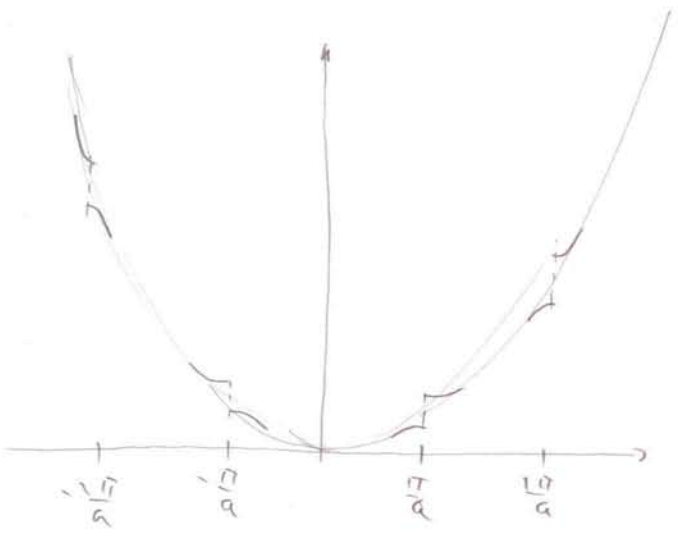
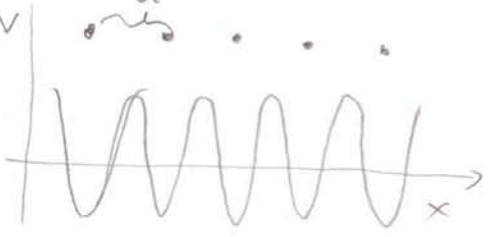
Trdna snov:



$V(x+a) = V(x) \Rightarrow \psi = u(x) e^{i k x}$ Blochova funkcija

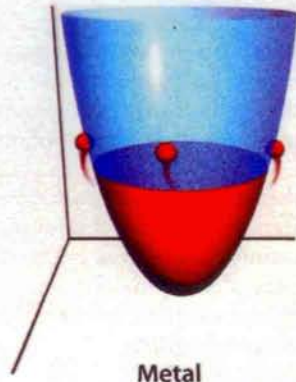
$u(x+a) = u(x)$

$k = \frac{2\pi}{a} \cdot \frac{n}{N}$ število atomov

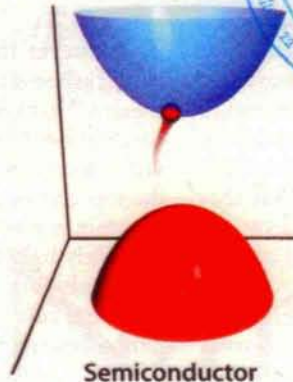


The Electrical Behavior of Nanotubes

A Split Personality



Metal

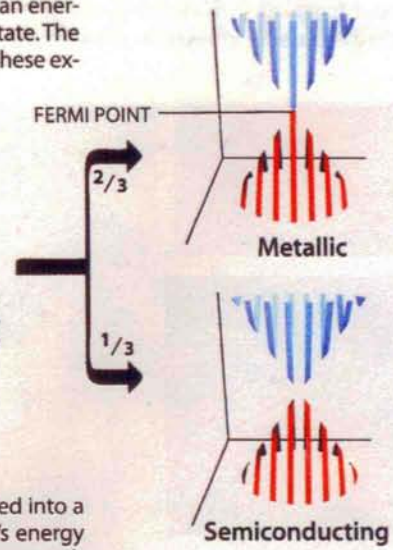
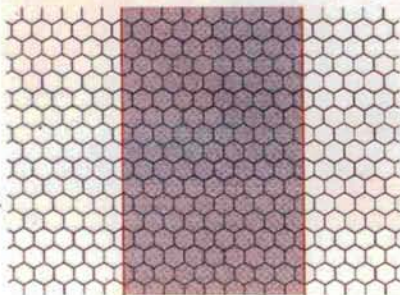


Semiconductor

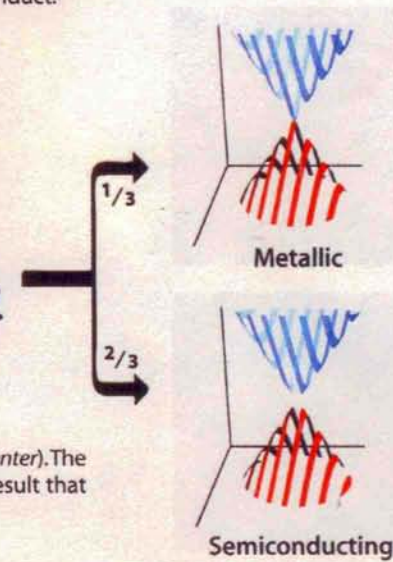
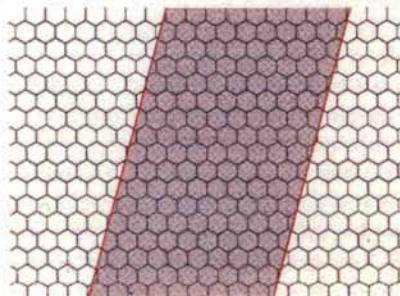


Graphite

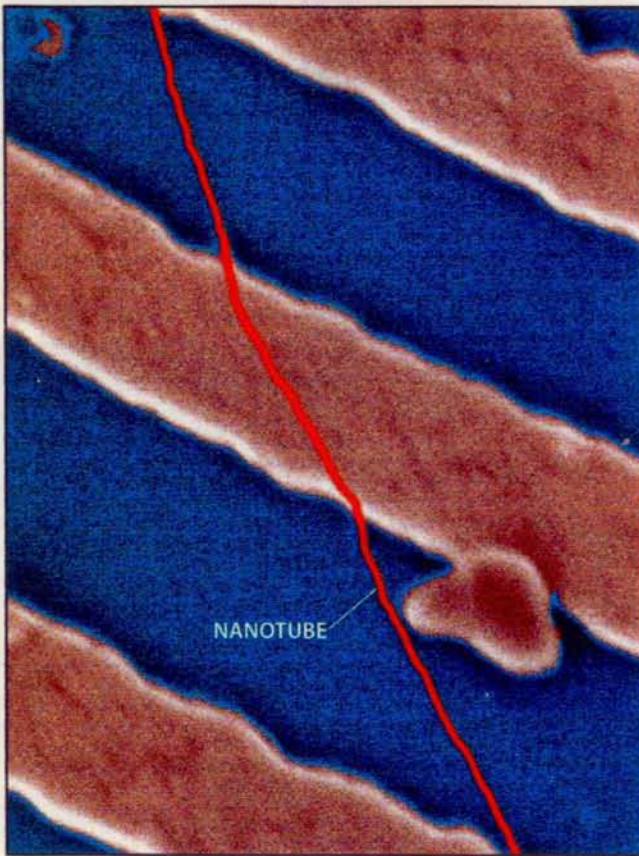
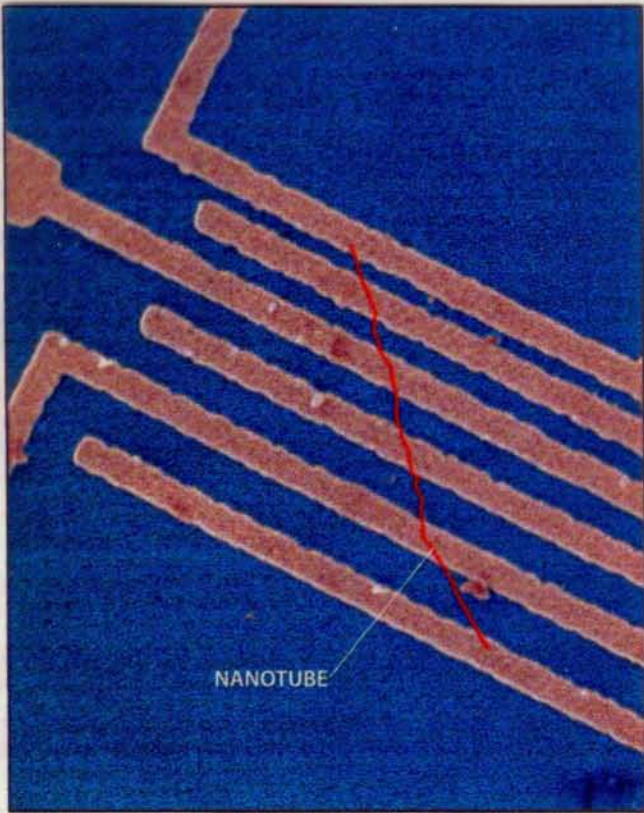
ELECTRICAL PROPERTIES of a material depend on the separation between the collection of energy states that are filled by electrons (red) and the additional "conduction" states that are empty and available for electrons to hop into (light blue). Metals conduct electricity easily because there are so many electrons with easy access to adjacent conduction states. In semiconductors, electrons need an energy boost from light or an electrical field to jump the gap to the first available conduction state. The form of carbon known as graphite is a semimetal that just barely conducts, because without these external boosts, only a few electrons can access the narrow path to a conduction state.



STRAIGHT NANOTUBES look like a straight swath cut from a sheet of graphite (left) and rolled into a tube (center). The geometry of nanotubes limits electrons to a select few slices of graphite's energy states (right). Depending on the diameter of the tube, one of these slices can include the narrow path that joins electrons with conduction states. This special point, called the Fermi point, makes two thirds of the nanotubes metallic. Otherwise, if the slices miss the Fermi point, the nanotubes semiconduct.



TWISTED NANOTUBES, cut at an angle from graphite (left), look a bit like barbershop poles (center). The slices of allowed energy states for electrons (right) are similarly cut at an angle, with the result that about two thirds of twisted tubes miss the Fermi point and are semiconductors.



PHILIP G. COLLINS AND PHAEDON AVOURIS

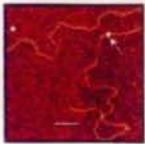
AS ULTRATHIN WIRES, carbon nanotubes could free up space in microchips for more devices, as well as solving heat and stability problems. At a little over a nanometer in diameter, this single-walled nanotube makes lines drawn by state-of-the-art photolithography look huge in comparison.



THE IDEA

OBSTACLES

FEASIBILITY



Chemical and Genetic Probes

Tagged strand of DNA

A nanotube-tipped atomic force microscope can trace a strand of DNA and identify chemical markers that reveal which of several possible variants of a gene is present in the strand.

This is the only method yet invented for imaging the chemistry of a surface, but it is not yet used widely. So far it has been used only on relatively short pieces of DNA.

3



Mechanical Memory

Nonvolatile RAM

A screen of nanotubes laid on support blocks has been tested as a binary memory device, with voltages forcing some tubes to contact (the "on" state) and others to separate (the "off" state).

The switching speed of the device was not measured, but the speed limit for a mechanical memory is probably around one megahertz, which is much slower than conventional memory chips.

2



Nanotweezers

Pincers five microns long

Two nanotubes, attached to electrodes on a glass rod, can be opened and closed by changing voltage. Such tweezers have been used to pick up and move objects that are 500 nanometers in size.

Although the tweezers can pick up objects that are large compared with their width, nanotubes are so sticky that most objects can't be released. And there are simpler ways to move such tiny objects.

2



Supersensitive Sensors

Oxygen sticks to tubes

Semiconducting nanotubes change their electrical resistance dramatically when exposed to alkalis, halogens and other gases at room temperature, raising hopes for better chemical sensors.

Nanotubes are exquisitely sensitive to so many things (including oxygen and water) that they may not be able to distinguish one chemical or gas from another.

3



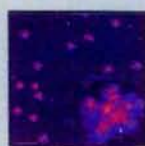
Hydrogen and Ion Storage

Atoms in hollow core

Nanotubes might store hydrogen in their hollow centers and release it gradually in efficient and inexpensive fuel cells. They can also hold lithium ions, which could lead to longer-lived batteries.

So far the best reports indicate 6.5 percent hydrogen uptake, which is not quite dense enough to make fuel cells economical. The work with lithium ions is still preliminary.

1



Sharper Scanning Microscope

Individual IgM antibodies

Attached to the tip of a scanning probe microscope, nanotubes can boost the instruments' lateral resolution by a factor of 10 or more, allowing clearer views of proteins and other large molecules.

Although commercially available, each tip is still made individually. The nanotube tips don't improve vertical resolution, but they do allow imaging deep pits in nanostructures that were previously hidden.

4



Superstrong Materials

Nanotube stress test

Embedded into a composite, nanotubes have enormous resilience and tensile strength and could be used to make cars that bounce in a wreck or buildings that sway rather than crack in an earthquake.

Nanotubes still cost 10 to 1,000 times more than the carbon fibers currently used in composites. And nanotubes are so smooth that they slip out of the matrix, allowing it to fracture easily.

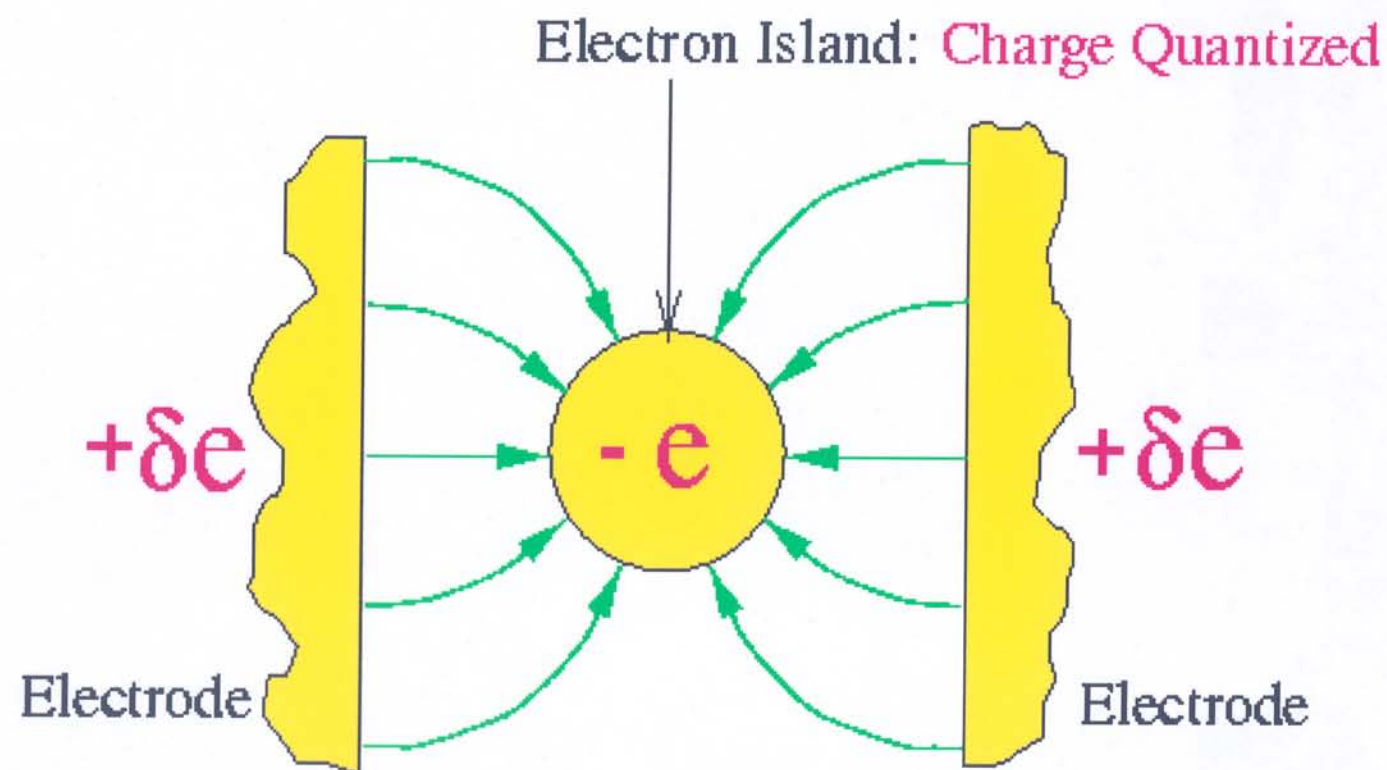
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Compiled by W. Wayt Gibbs, staff writer

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Basics of Single-Electron Tunneling

Coulomb-Blockade-Effect (CB)



$$E_c = e^2/2C$$

$$R < 1\mu\text{m}, \epsilon = 10 \quad \blacktriangleright \quad C < 10^{-15} \text{ F} \quad \blacktriangleright \quad E_c > kT \text{ @ } T = 1 \text{ K}$$

Advar

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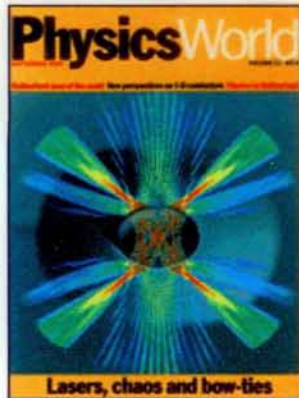
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Lasers, chaos and bow-ties

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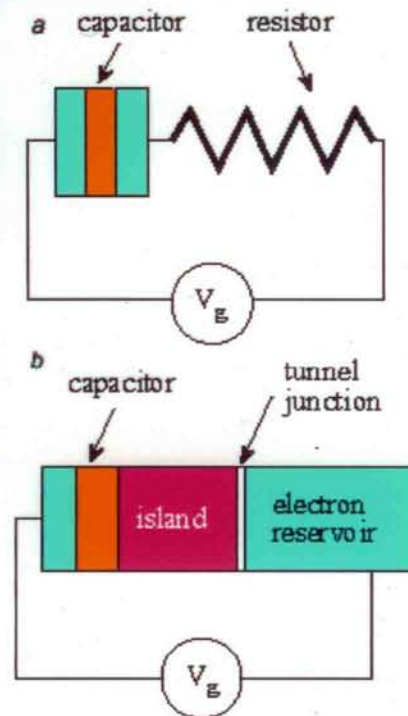
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3: An electron in a box

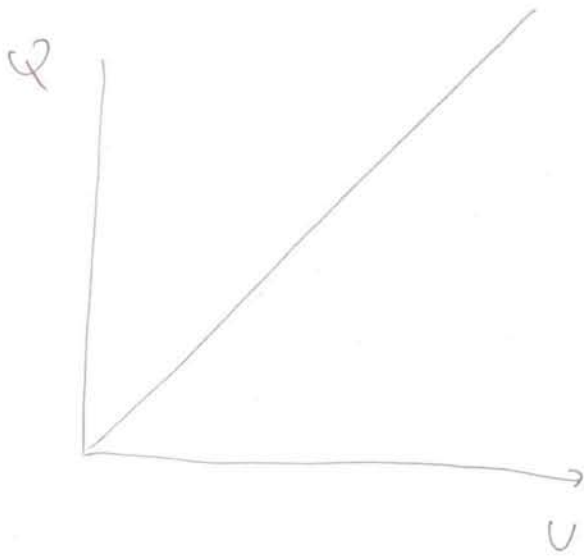
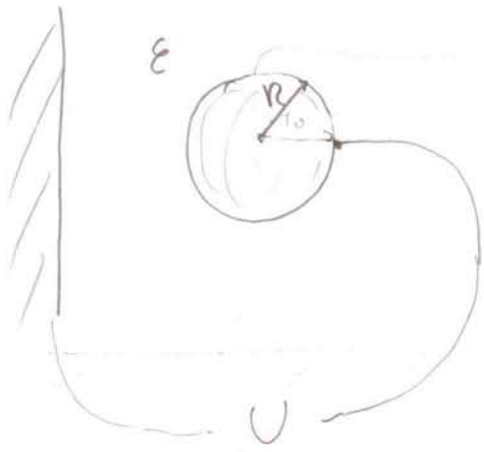
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(a) When a capacitor is charged through a resistor, the charge on the capacitor is proportional to the applied voltage and shows no sign of quantization. (b) When a tunnel junction replaces the resistor, a conducting island is formed between the junction and the capacitor plate. In this case the average charge on the island increases in steps as the voltage is increased (c). The steps are sharper for more resistive barriers and at lower temperatures.

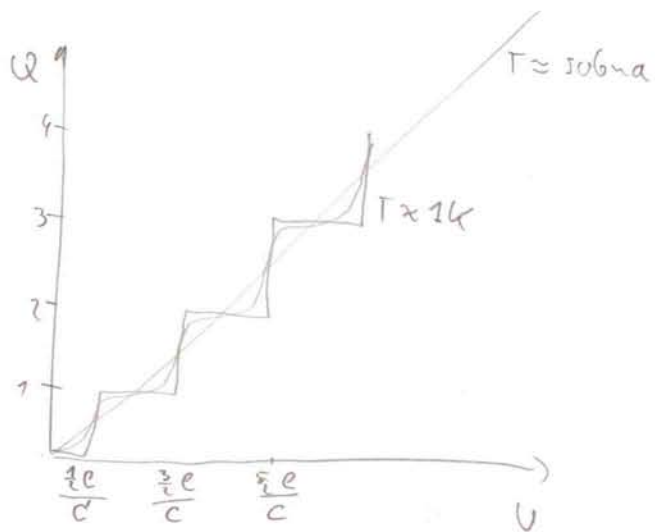
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Coulomb - blokada



$$Q = C \cdot U$$

$$C = \epsilon \epsilon_0 \cdot 4\pi R$$



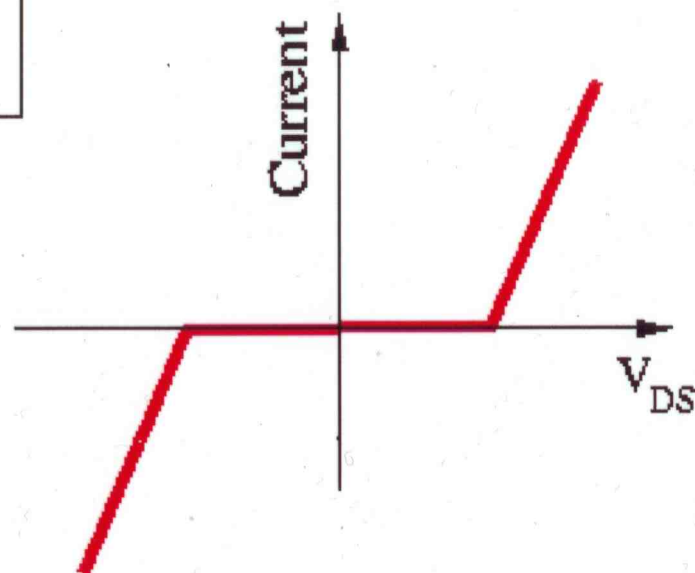
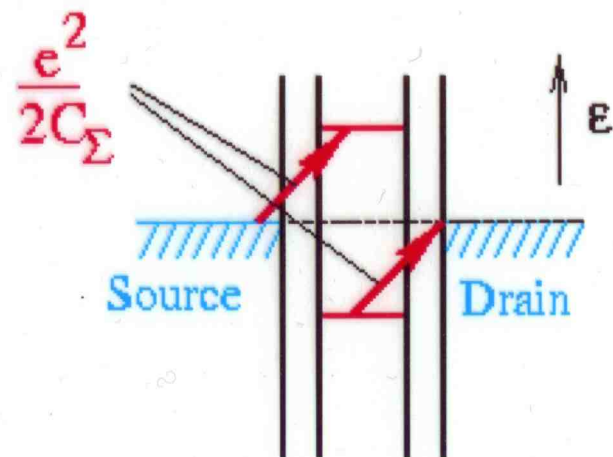
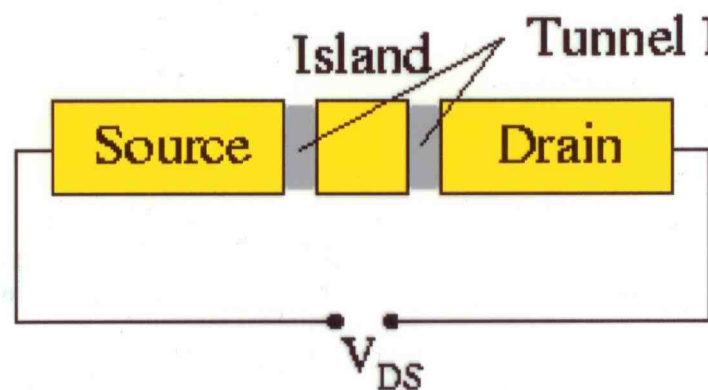
$$E = \frac{1}{2} Q U = \frac{1}{2} \frac{Q^2}{C}$$

$$r = 1 \mu\text{m} \quad \epsilon = 10 \quad \epsilon_0 = 8.8 \cdot 10^{-12} \frac{\text{As}}{\text{Vm}}$$

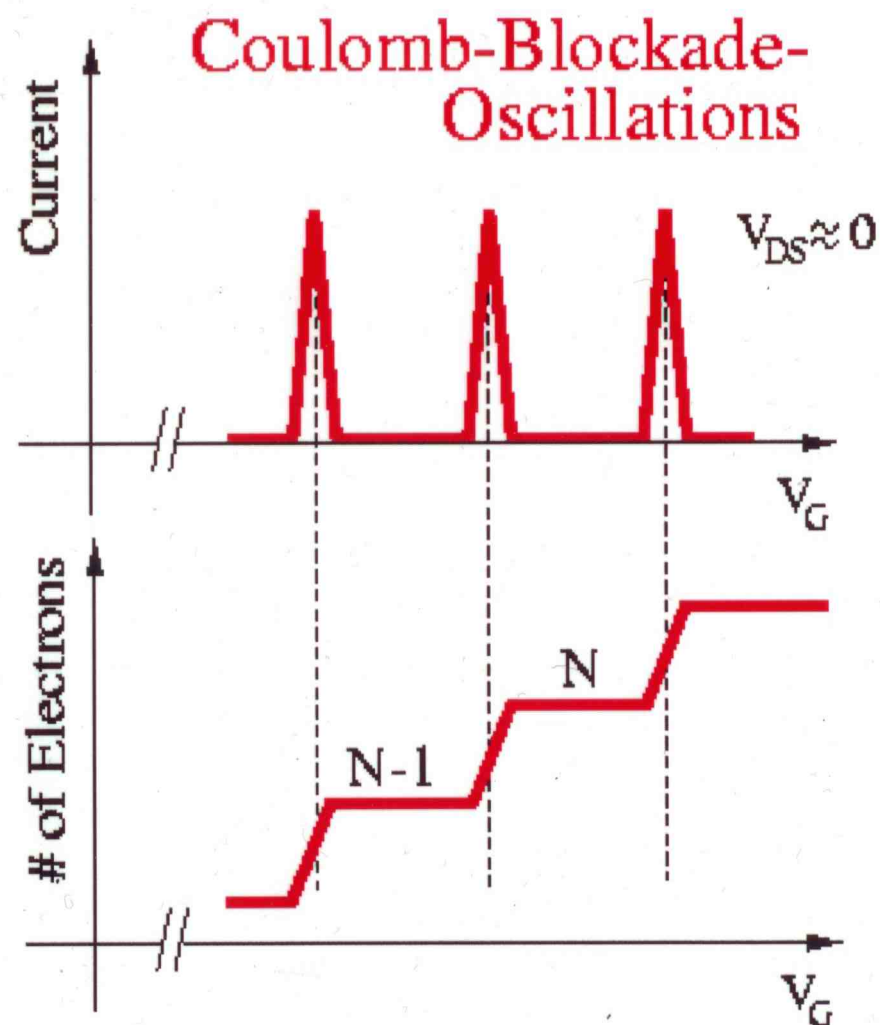
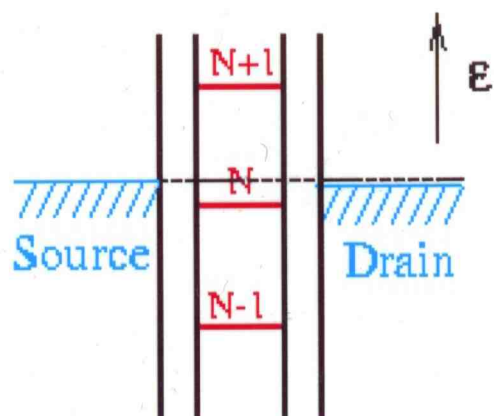
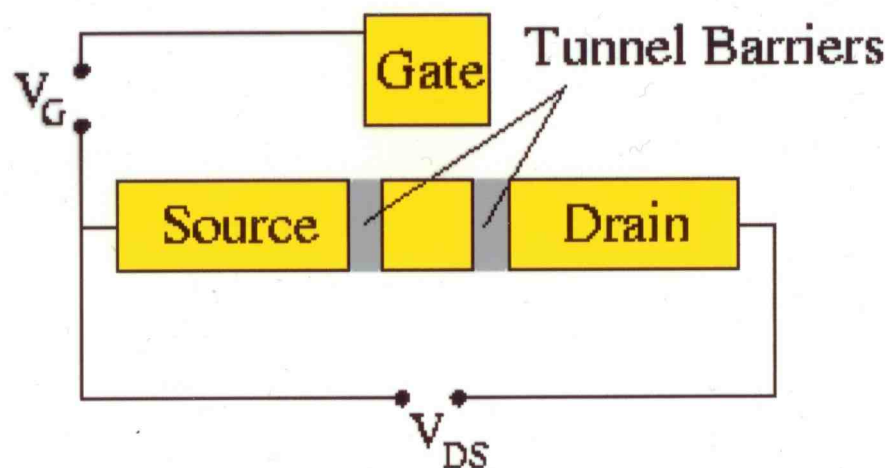
$$C \approx 10^{-15} \text{F}$$

$$Q = 1e \Rightarrow E = 10^{-6} \text{eV} \approx kT (T = 1\text{K})$$

Coulomb-Blockade in Electrical Transport

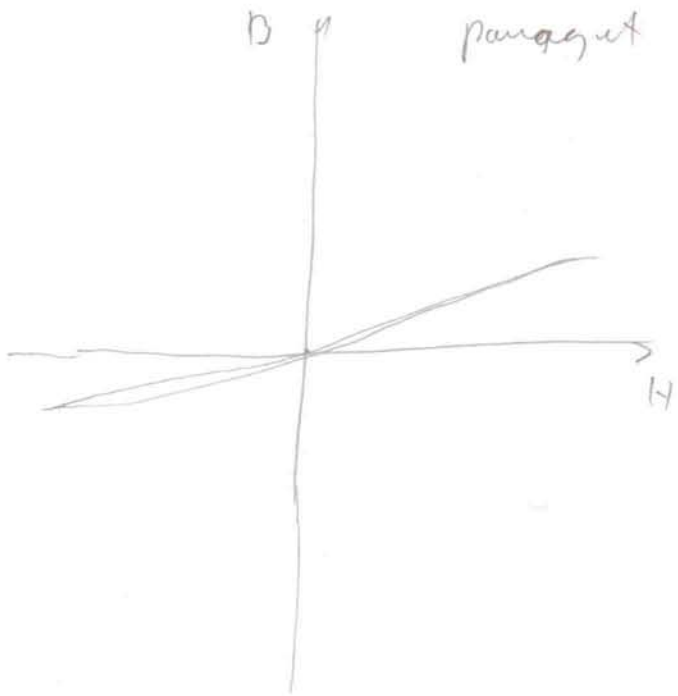


Single-Electron-Transistor (SET)



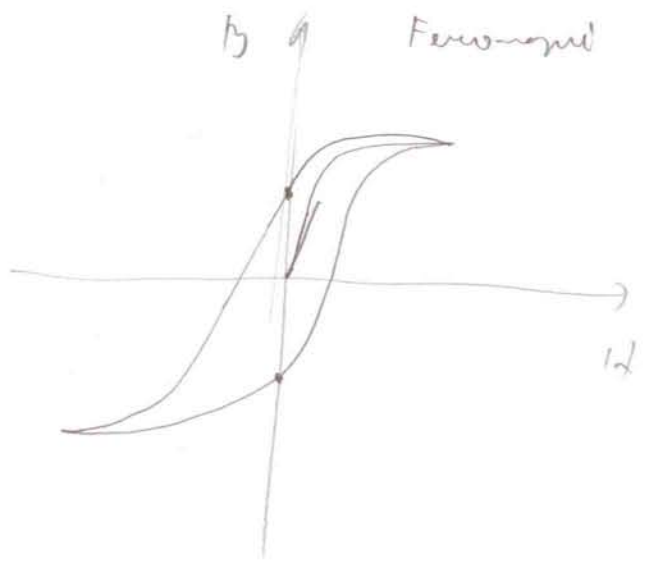
Proposed: D.V. Averin, K.K. Likharev, IEEE Trans. Magn. 23, 1142 (1987)

First Realisation: T.A. Fulton and G.J. Dolan, Phys. Rev. Lett. 59,109 (1987)



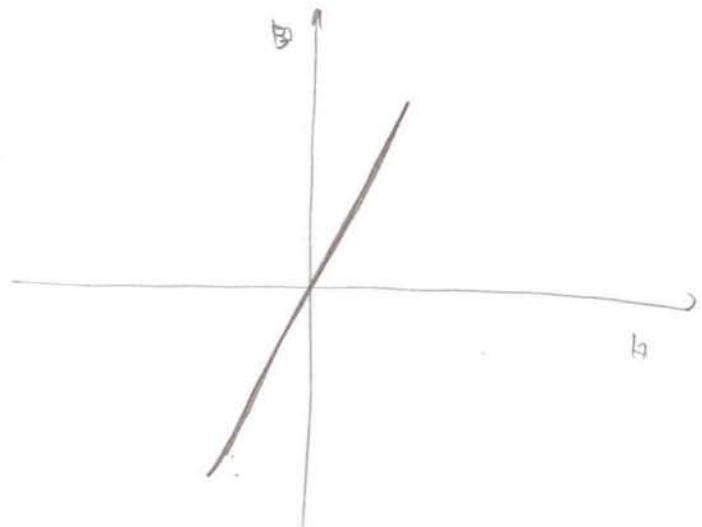
$$B = \mu \mu_0 H$$

$$\mu \approx 1$$



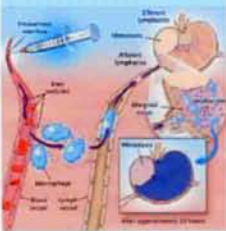
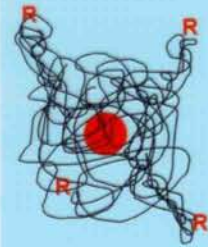
$$\mu \approx 1000$$

Superparamagnet



SPION = Superparamagnetic Iron Oxide Nanoparticle

Drug Delivery:



Particles with attached drug can be injected and guided through the body by application of an external field.

??? WHY SUPERPARAMAGNETIC PARTICLES ???

Size of the superparamagnetic particle:

Magnetic active core = 2-3 nm

Coating (polymer, proteins, functional rest groups R) ~ 10 nm

Size of cell = 10 – 100 μm

virus = 20 – 450 nm

protein = 5 – 50 nm

gene = 2* (10 - 100) nm²

Design of the particle:

- Attachment of R -> Particles enter the cells
Particles can be recognized by the organism
Drugs can be attached to the particle
R influences the toxicity for the organism

APPLICATIONS

Hyperthermia

Therapeutic effect on several types of tumours

- Injection of superparamagnetic nanoparticles
- translocation of the particles to the tumour
- uptake of the nanoparticles by cancerous cells
- application of an external alternative magnet field
-> provides energy for the magnetic moments to change magnetisation direction
-> Superparamagnetic relaxation: dissipated energy = heat
- Cancerous cells have higher temperature sensitivity than healthy cells
- No danger of thrombosis, no remanent magnetisation!

