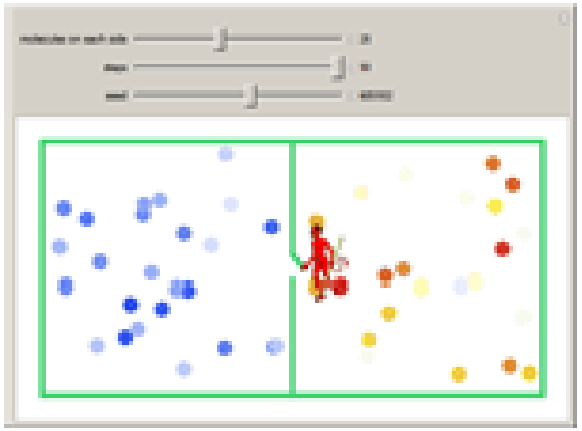
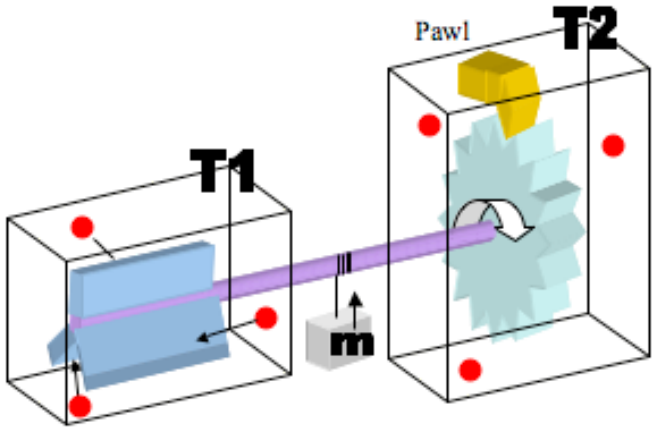
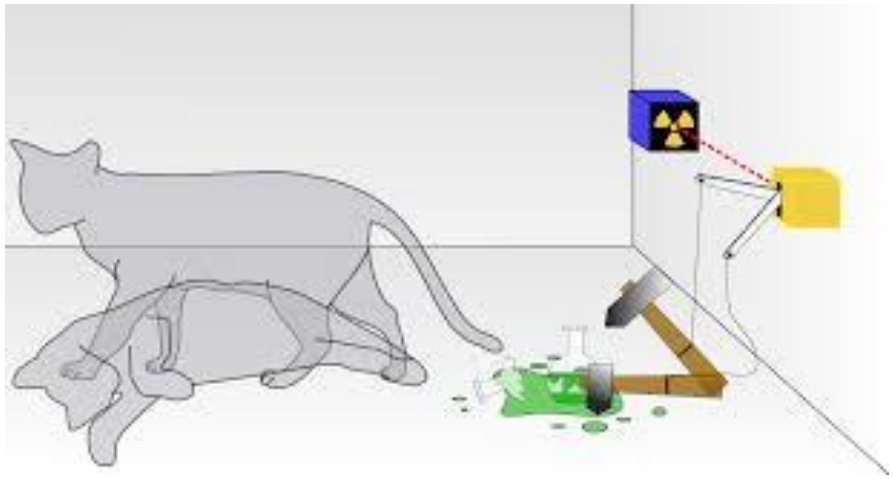
Maxwell Demon

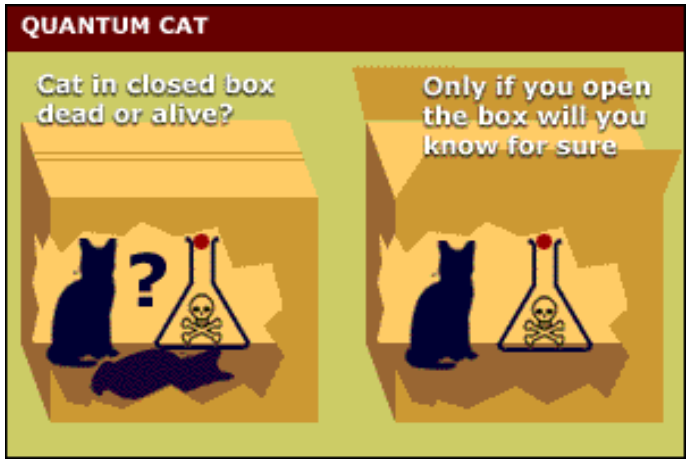


Brownian ratchet (Feymman 1962)

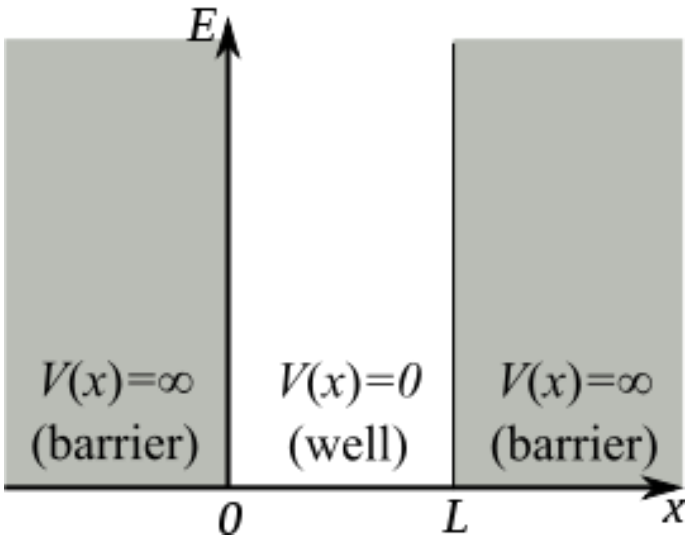


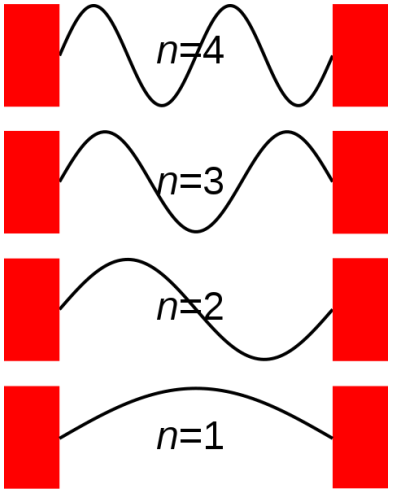
Quantum Cat




QUANTUM CAT
Cat in closed box dead or alive?
?
Only if you open the box will you know for sure

Quantum box

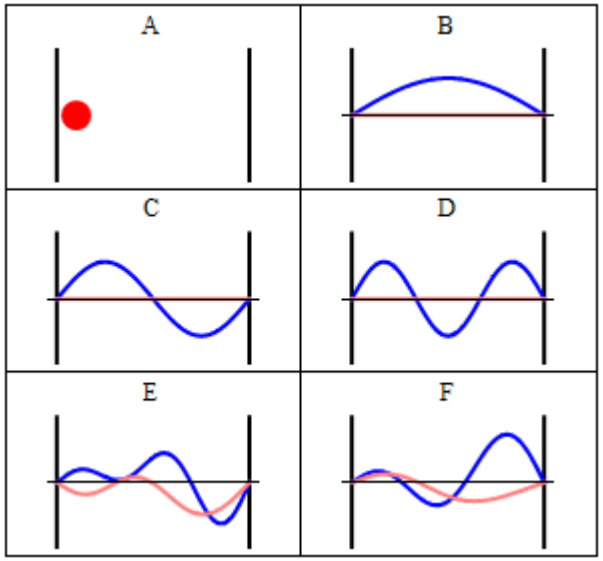




$$\psi_n(x) = C\,\mathrm{sen}(k_n x) = C\,\mathrm{sen}\left(\frac{n}{L}x\right), \qquad \text{n=1,2,3, ...}$$

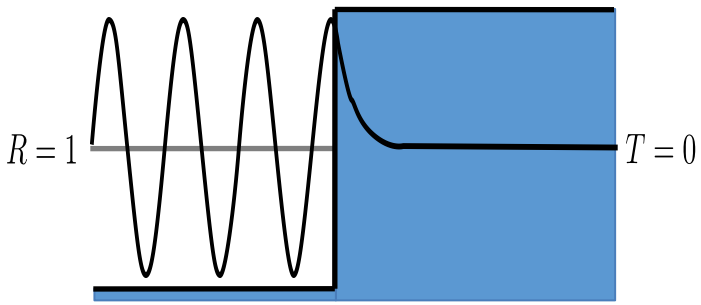
$$k_n = \sqrt{\frac{2mE_n}{\hbar^2}}$$

$$E_n = \frac{n^2\hbar^2}{2mL^2}$$

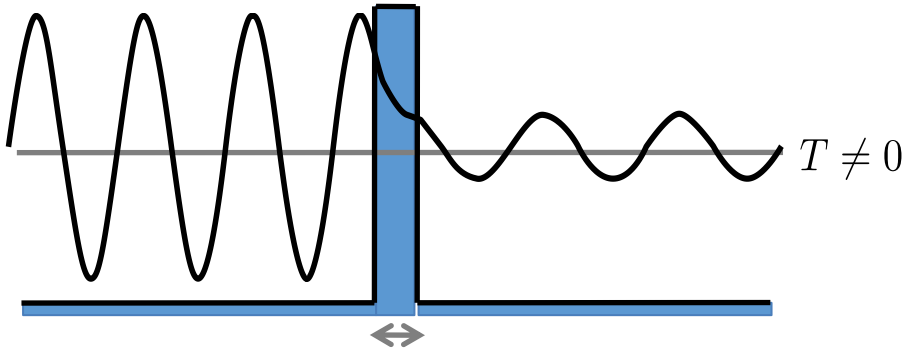


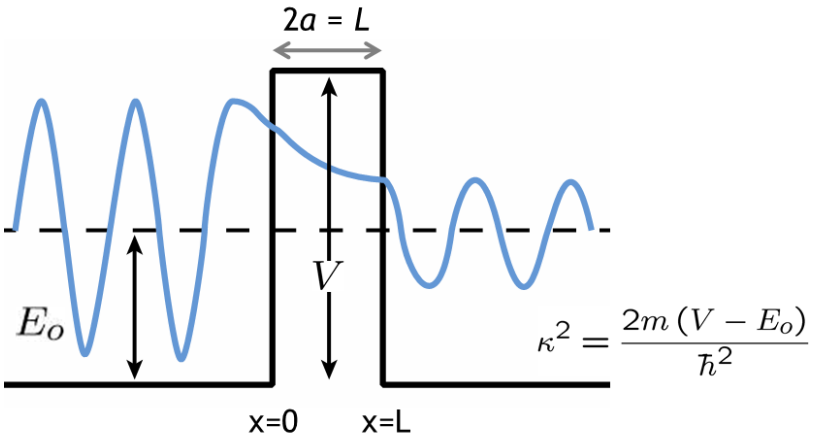
Quantum Tunneling Through a Thin Potential Barrier

Total Reflection at Boundary

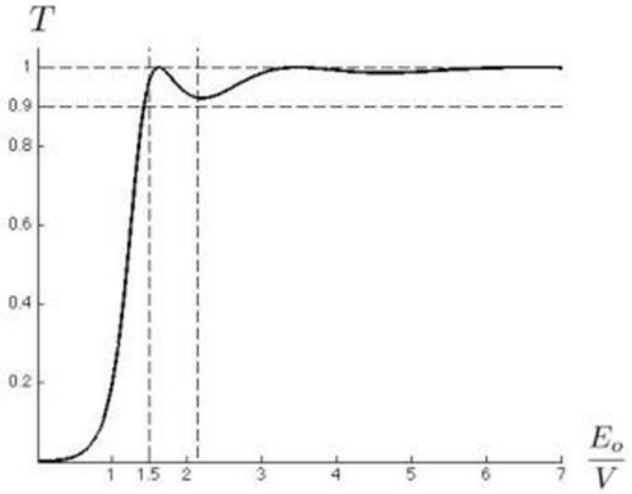


Frustrated Total Reflection (Tunneling)





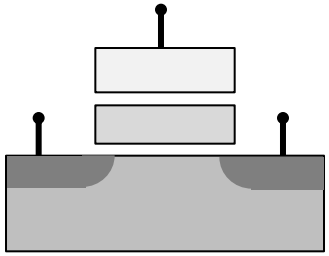
$$\kappa^2 = \frac{2m\,(V - E_o)}{\hbar^2}$$



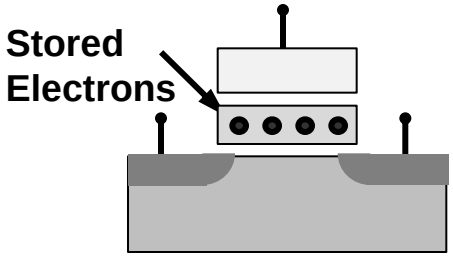
$$T = \left|\frac{F}{A}\right|^2 = \frac{1}{1 + \frac{1}{4}\frac{V^2}{E_o(V-E_o)}\sinh^2(2\kappa a)}$$

Flash Memory

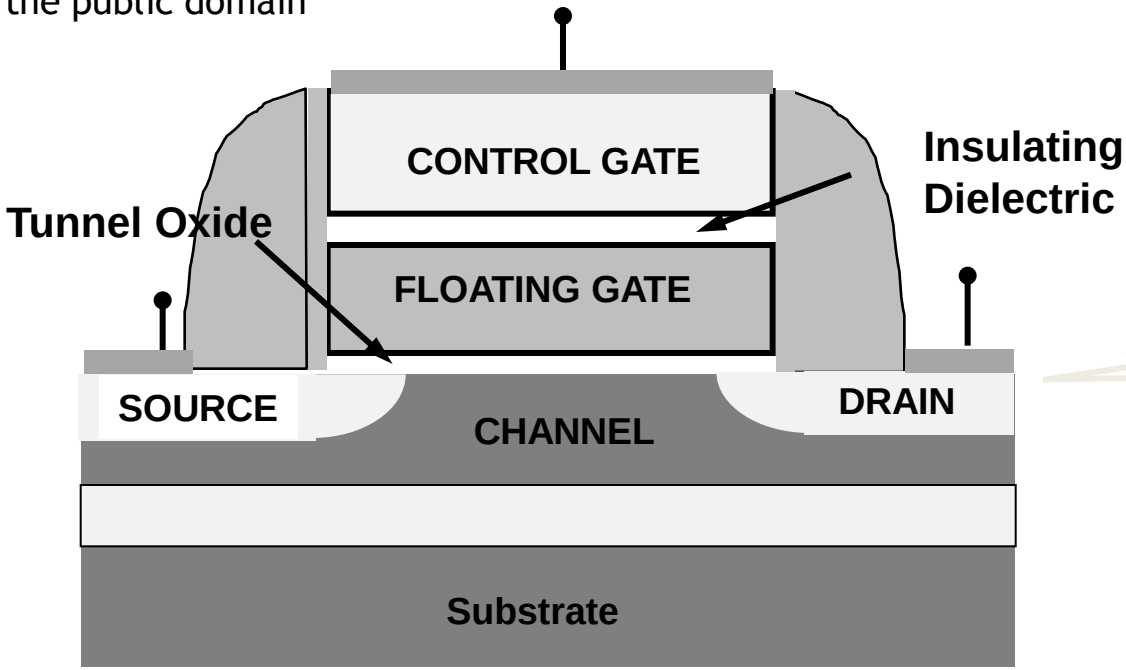
Image is in the public domain

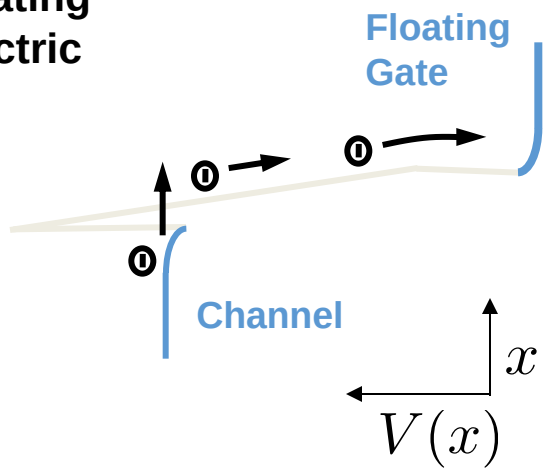


Erased
"1"



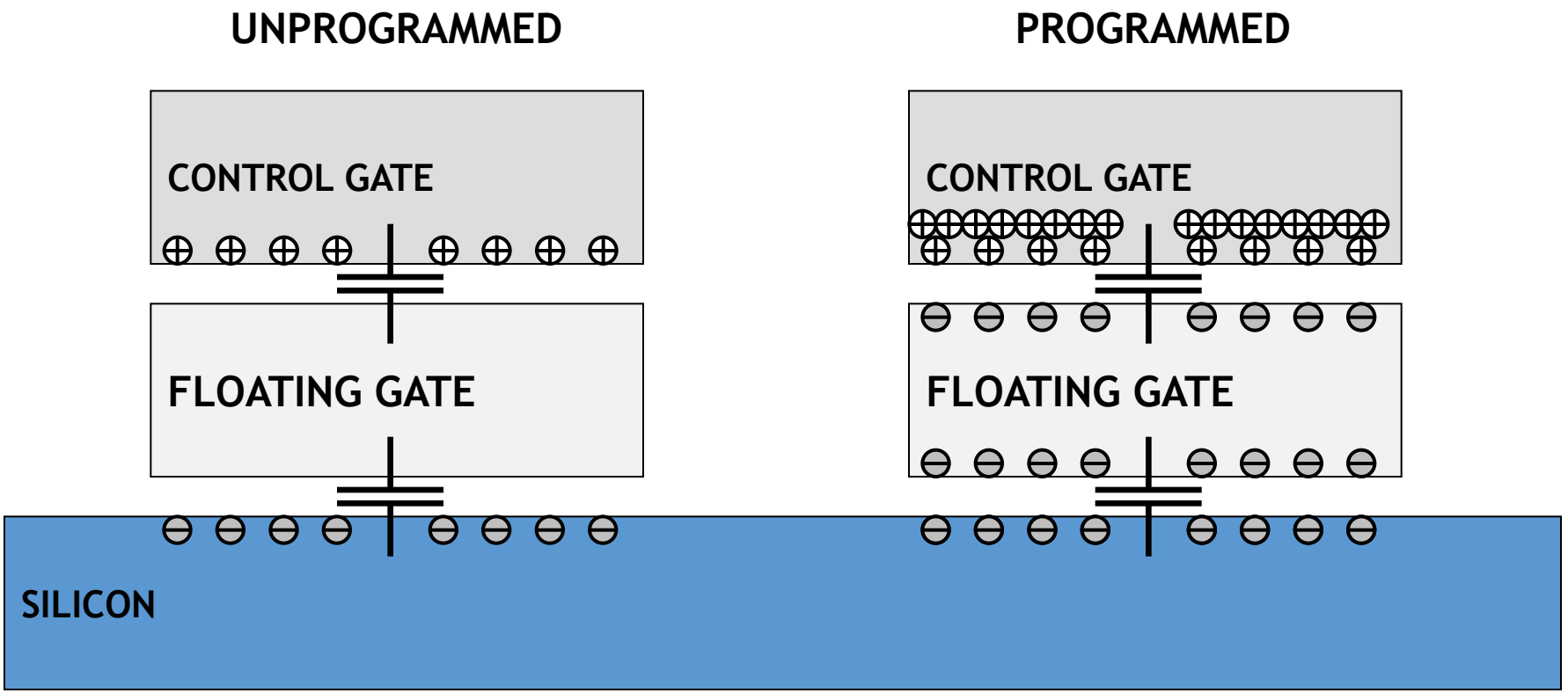
Programmed
"0"





Electrons tunnel preferentially when a voltage is applied

Reading Flash Memory



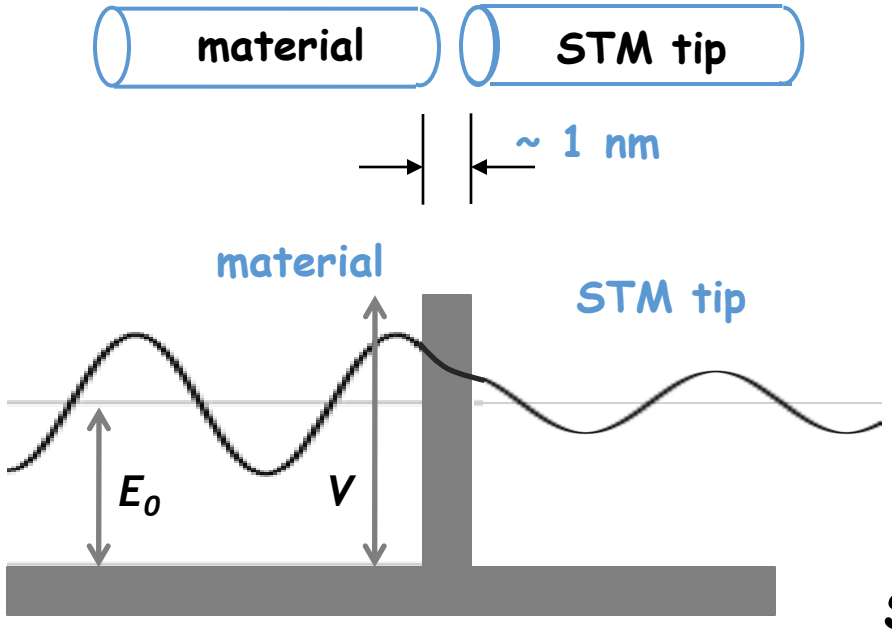
To obtain the same channel charge, the programmed gate needs a higher control-gate voltage than the unprogrammed gate

How do we WRITE Flash Memory ?

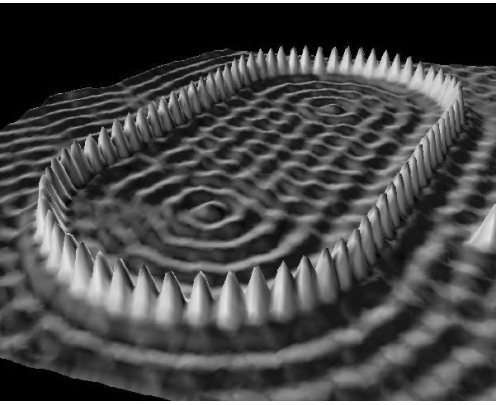
Application of Tunneling:
Scanning Tunneling Microscopy (STM)

Due to the quantum effect of "barrier penetration," the electron density of a material extends beyond its surface:

One can exploit this to measure the electron density on a material's surface:



Sodium atoms on metal:



← STM images →

Image originally created by IBM Corporation

Single walled carbon nanotube:

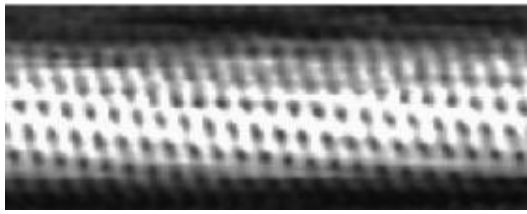
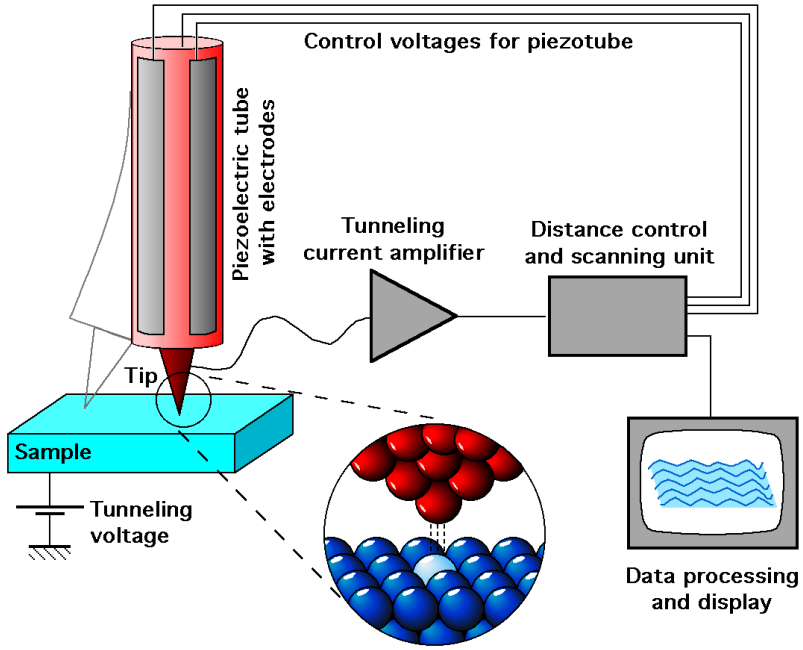


Image is in the public domain

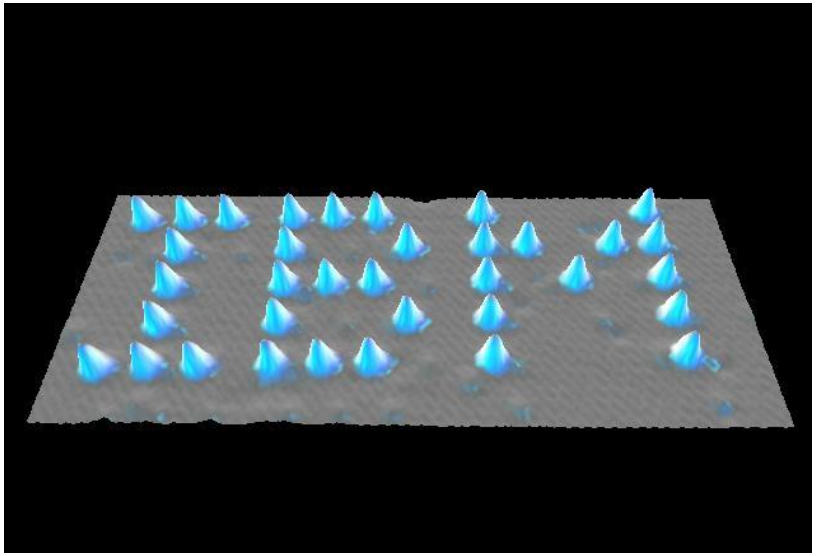
Scanning Tunneling Microscopes

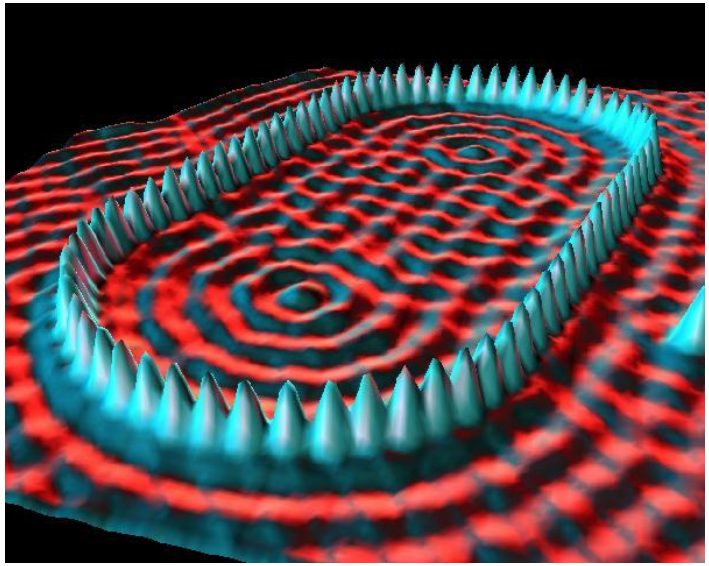
- The Scanning Tunneling Microscope was invented in 1981 by Gerd Binnig and Heinrich Rohrer
- When a metal tip, usually made of tungsten or platinum-iridium, is brought within .4-.7nm of the sample, electrons tunnel across the gap and create a current in the tip
- This current is then fed to a computer and used to generate an image of the atomic surface of the sample



At this distance the coulomb force between the tip and an atom of the sample is actually enough to move the atom

This has allowed physicists to create images and structures on the atomic level





Images courtesy of IBM

Force Sensors

A UK company is developing flexible force sensors that use quantum tunneling

These sensors are made out of Quantum Tunneling Composite materials

QTC's are essential non-conducting in their normal state

When flexed by an applied force, the atoms of the QTC are brought close enough so that tunneling can occur

Tunneling changes the QTC from an insulator to a conductor with a predictable exponential decay in resistance

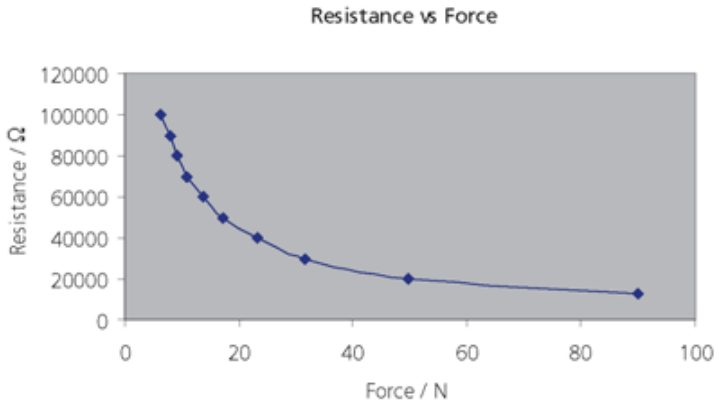
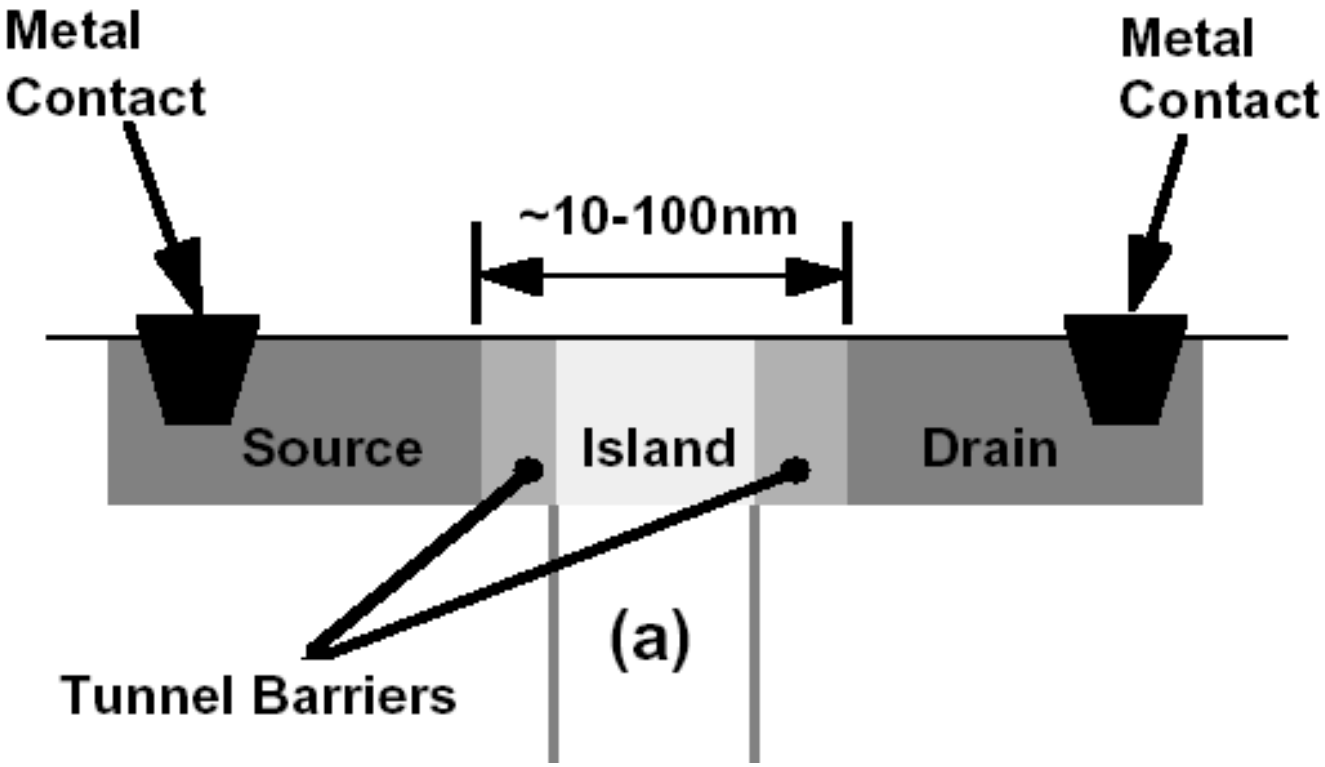


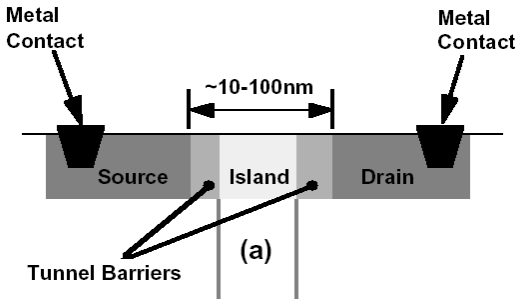
Image courtesy of Peratech

Resonant Tunnelling Diodes

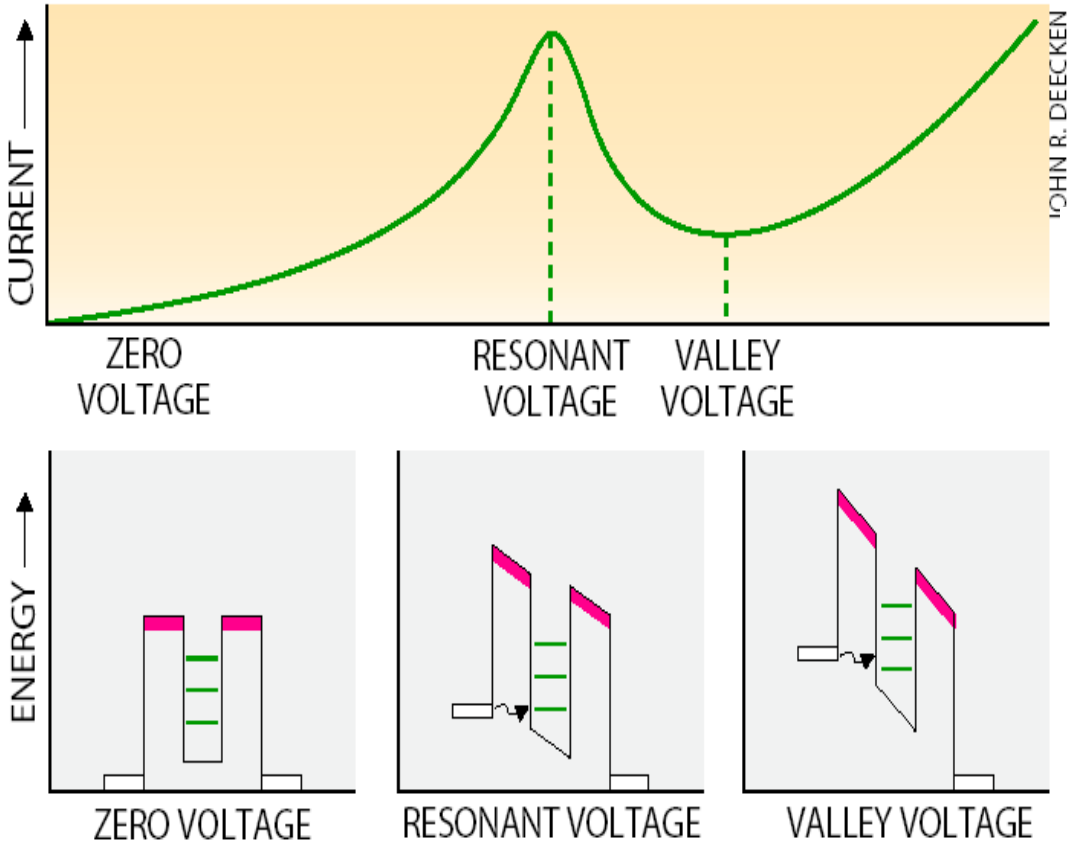


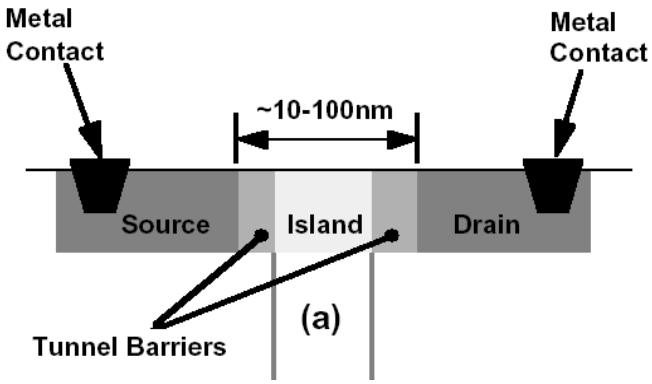
Resonant Tunnelling Diodes

- Fundamentally different operating principle
  - Quantisation
  - Quantum tunnelling
- Computation comes from Negative Differential Resistance (NDR)



Negative Differential Resistance





Need high peak to Valley Current Ratio (PVCR)
PVCR of 2-4 desirable