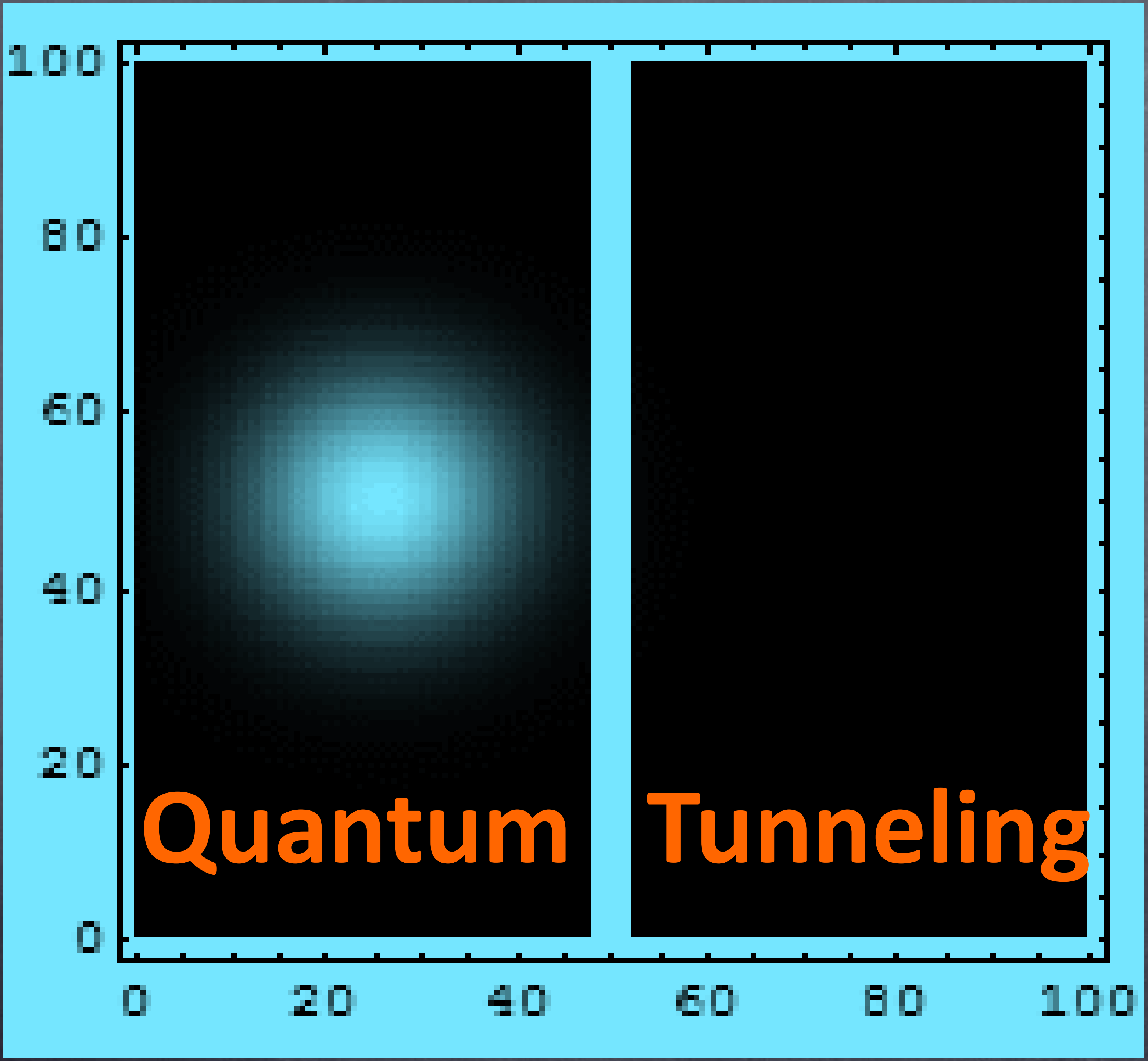

100
80
60
40
20
0
0
20
40
60
80
100
Quantum
Tunneling

History of Quantum Tunneling

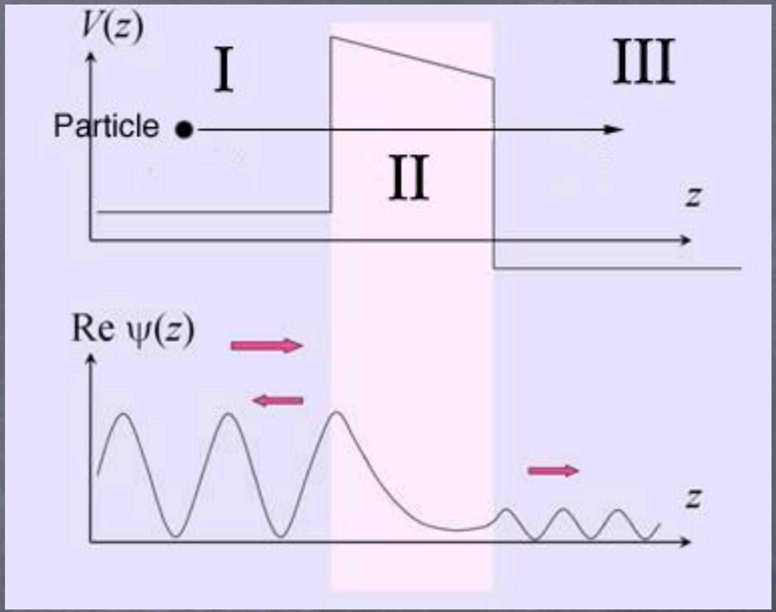
- Consequence of the wave nature of matter
- First used to explain alpha decay of heavier elements in 1928 by George Gamow
- Shown experimentally by Leona Esaki in 1958 in the tunneling diode

What is Quantum Tunneling?

- At the quantum level, matter has corpuscular and wave-like properties
- Tunneling can only be explained by the wave nature of matter as described by quantum mechanics
- Classically, when a particle is incident on a barrier of greater energy than the particle, reflection occurs
- When described as a wave, the particle has a probability of existing within the barrier region, and even on the other side of it

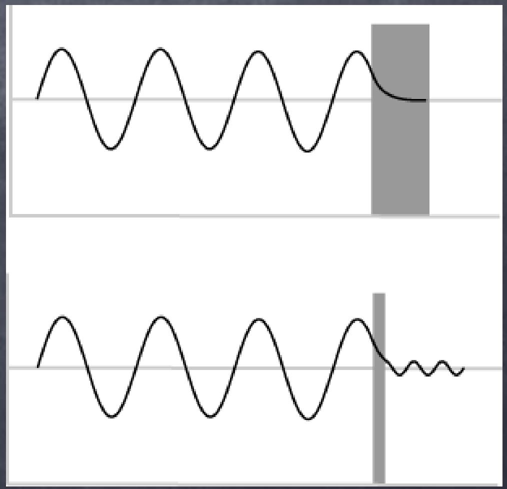
How Can This Be?

- Solutions to the wave equation have the general form (I)
- In the barrier region, the solution becomes (II)
- The wave function decays exponetially in the barrier region
- If some portion of the wavefunction still exists on the other side of the barrier, transmission has occurred
- The width of the barrier is the most prominent factor in determining the probability of transmission



(I) $Ae^{i\kappa x} + Be^{-i\kappa x}$

(II) $Ce^{\kappa x} + De^{-\kappa x}$



Images courtesy of Wikipedia

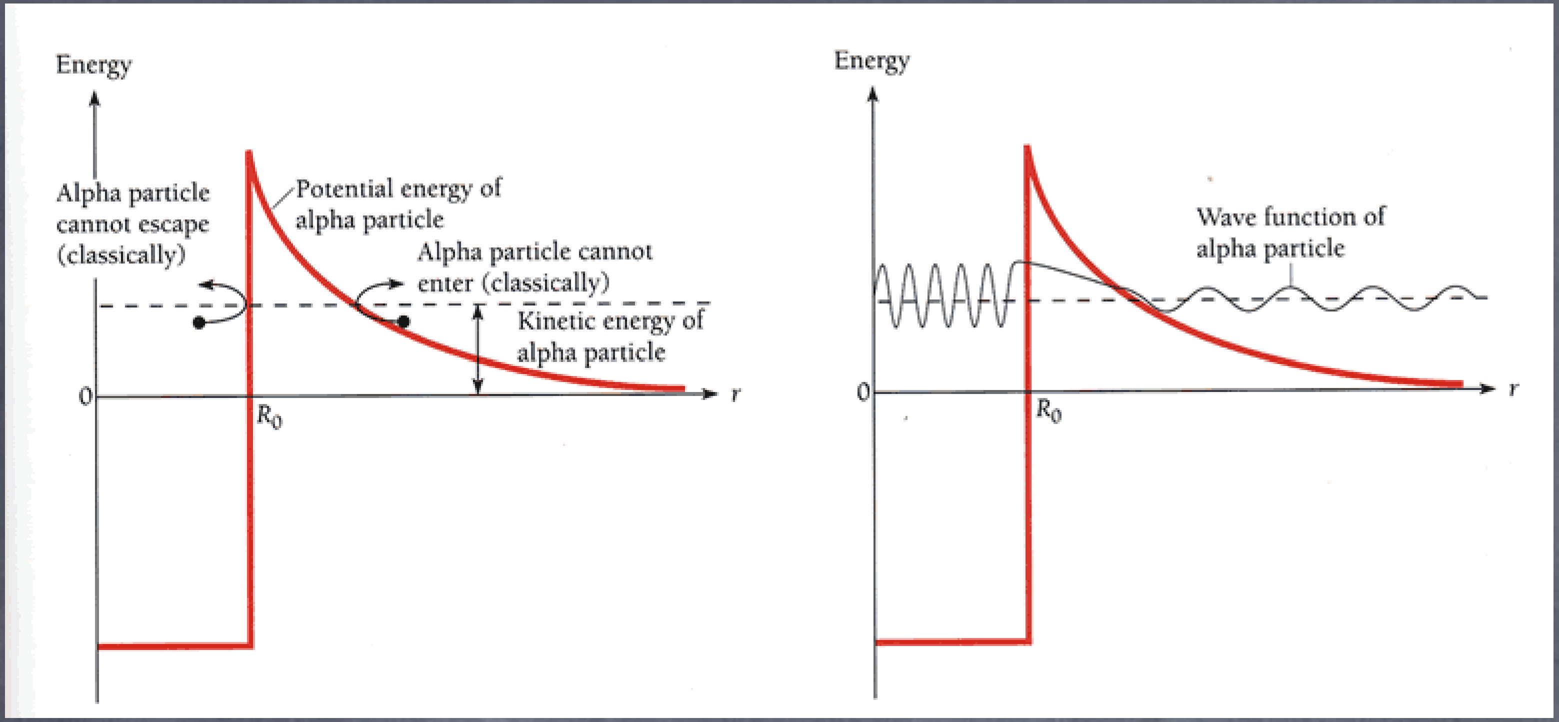
Wave Packet Demonstration

https://physics.weber.edu/schroeder/software/BarrierScattering.html

Tunneling & α-Decay

$$ {}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He $$

- George Gamow used tunneling to explain α-decay in Uranium 238
- The α particle does not have enough kinetic energy to escape the nucleus
- There is a chance, due to it's wave function, that it will escape the potential barrier of the nucleus boundary
- Due to the exponential decay nature of the wave function in the barrier region, the width of the barrier can manifest itself in the half-life of the isotope



Classically, a particle cannot overcome a potential barrier bigger than its kinetic energy but quantum mechanically the process might happen with a certain probability.

The two competing forces: attractive nuclear force and Coulomb repulsion create a potential barrier. In principle, the alpha is bound in the nucleus but it can escape by tunnel effect.

Even if the alpha has energies below the Coulomb “barrier”,
it can “tunnel” through it allowing the decay.

Tunneling & Microchip Development

- As microchip developers create smaller production processes, we reach the limit of classical computer technology
- **The feature size of the most advanced microchip today is 45 nm**
- With such small widths, the electrons in the channel can tunnel out

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 air gap and create a current in the tip.
- The current is highly sensitive to the thickness of the air gap.
- This current is then fed to a computer and used to generate an image of the atomic surface of the sample

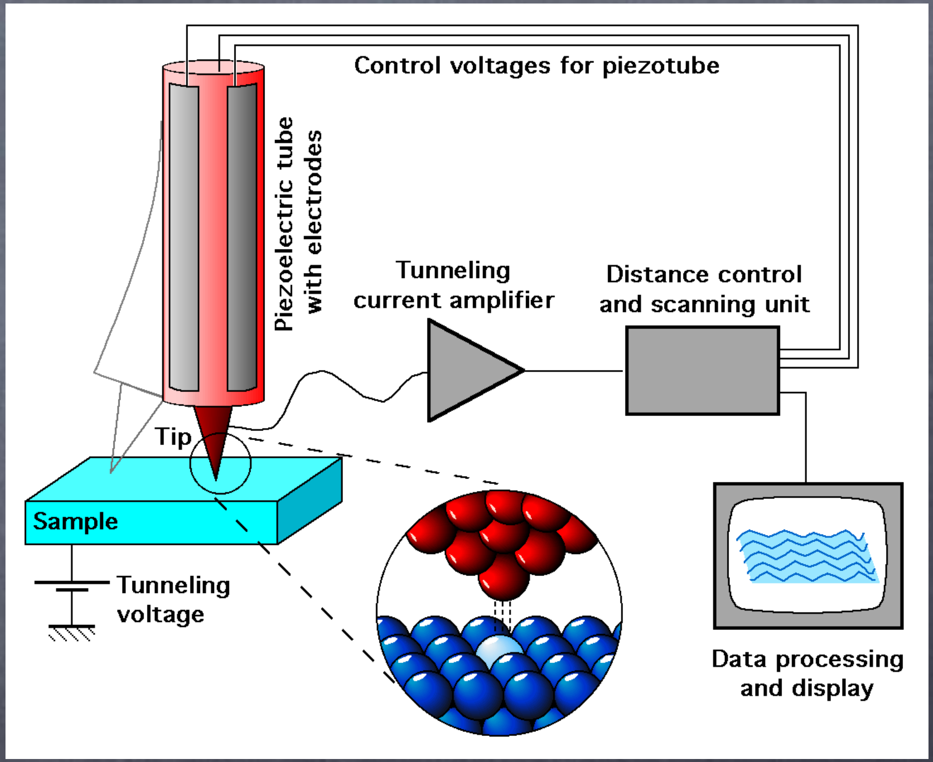
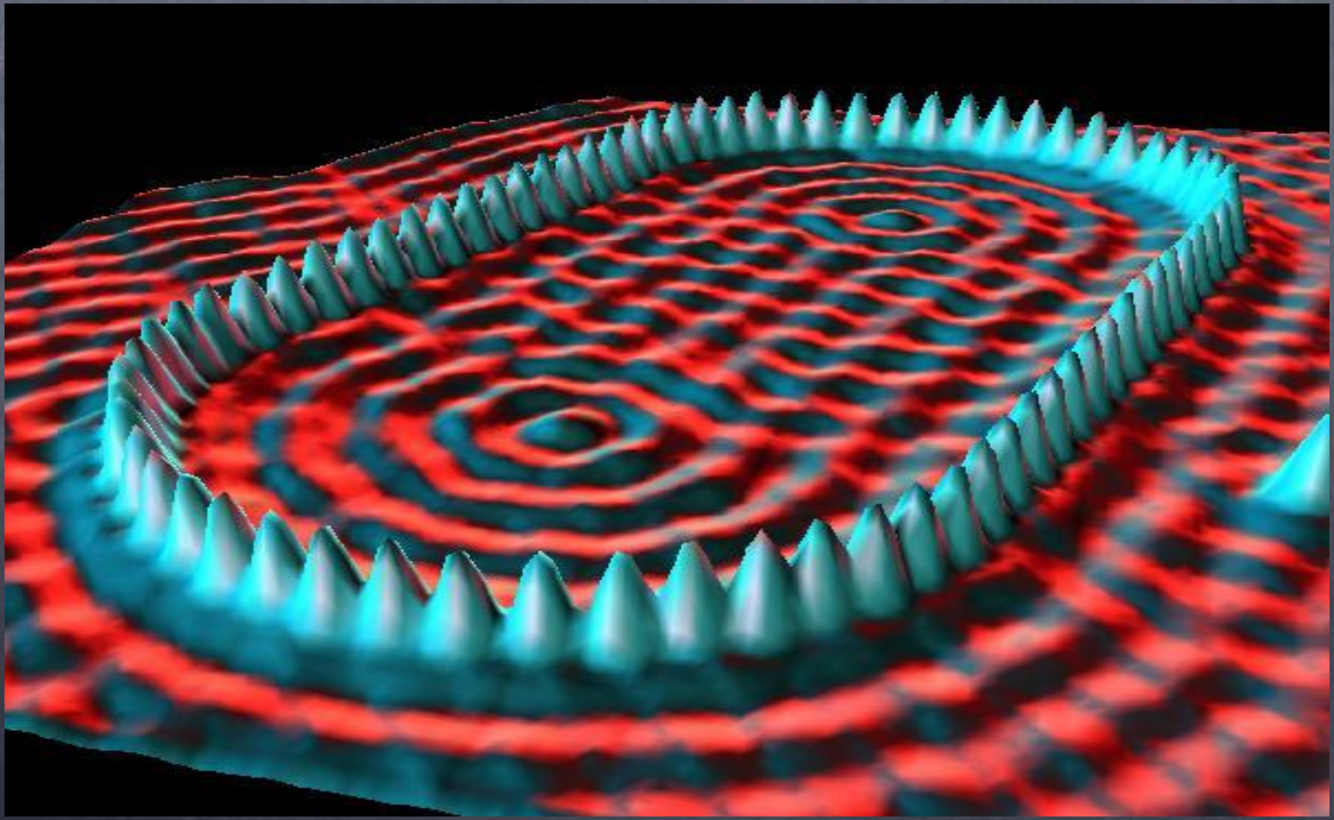
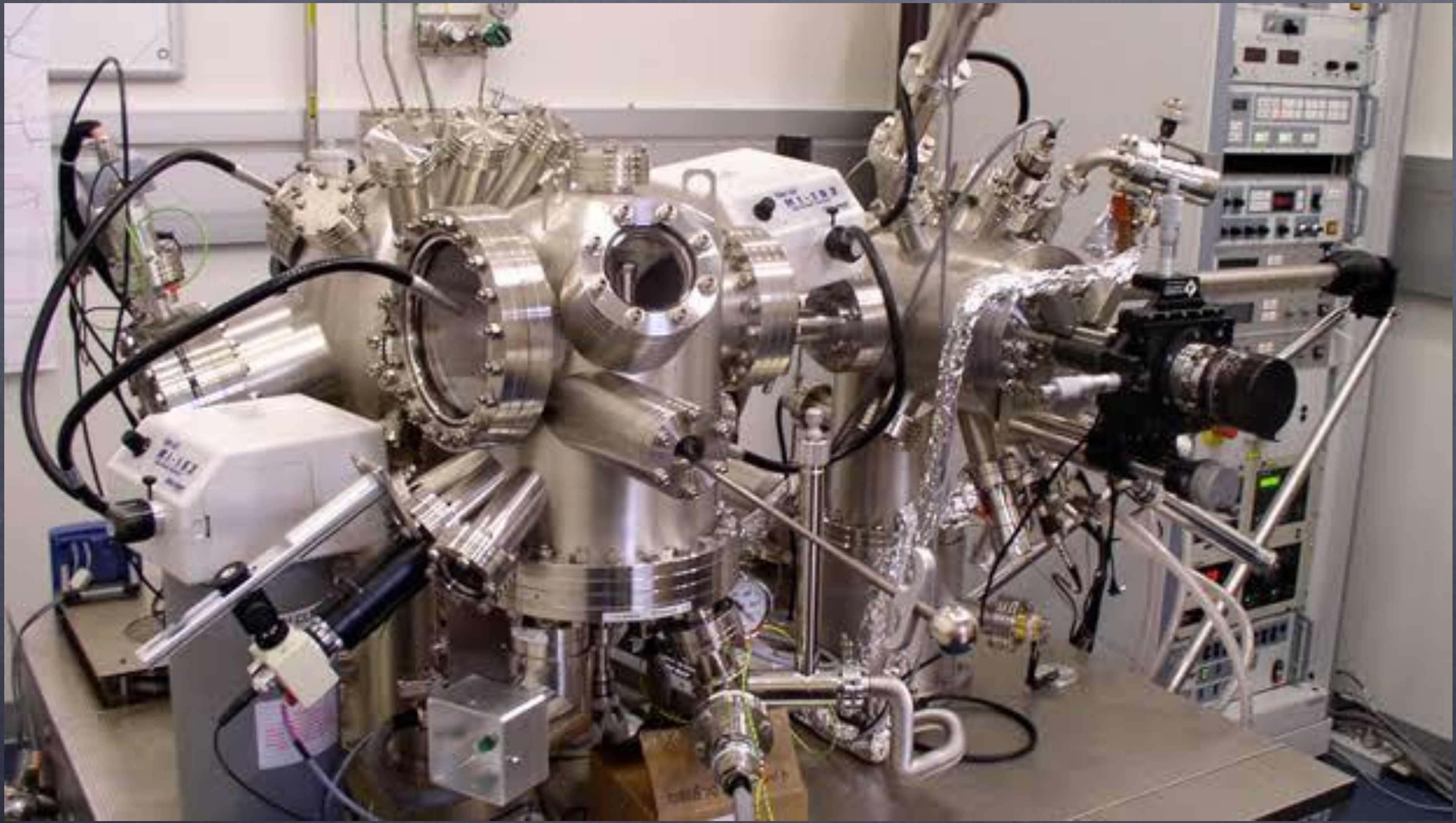


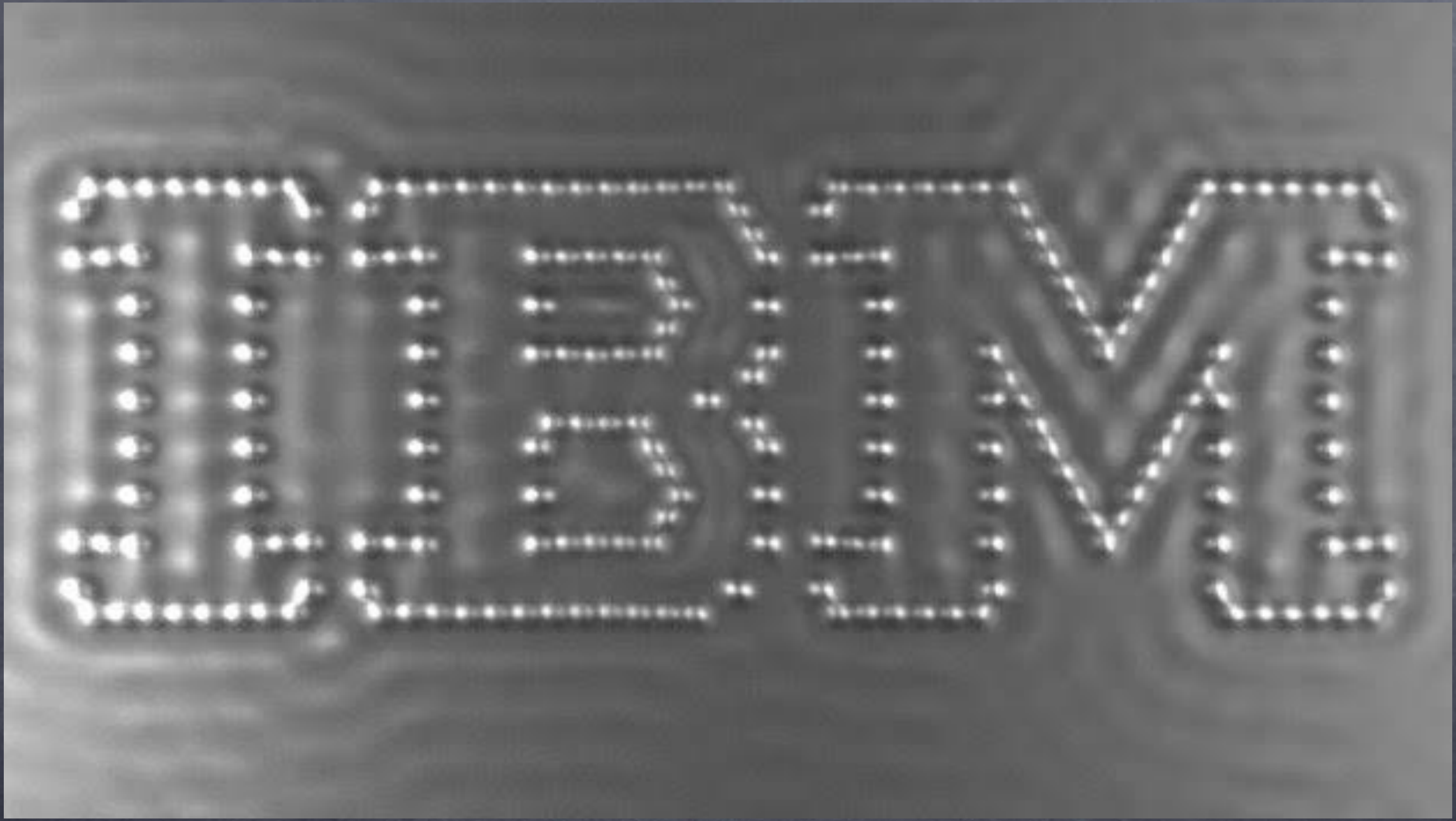
Image courtesy of Wikipedia

- 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

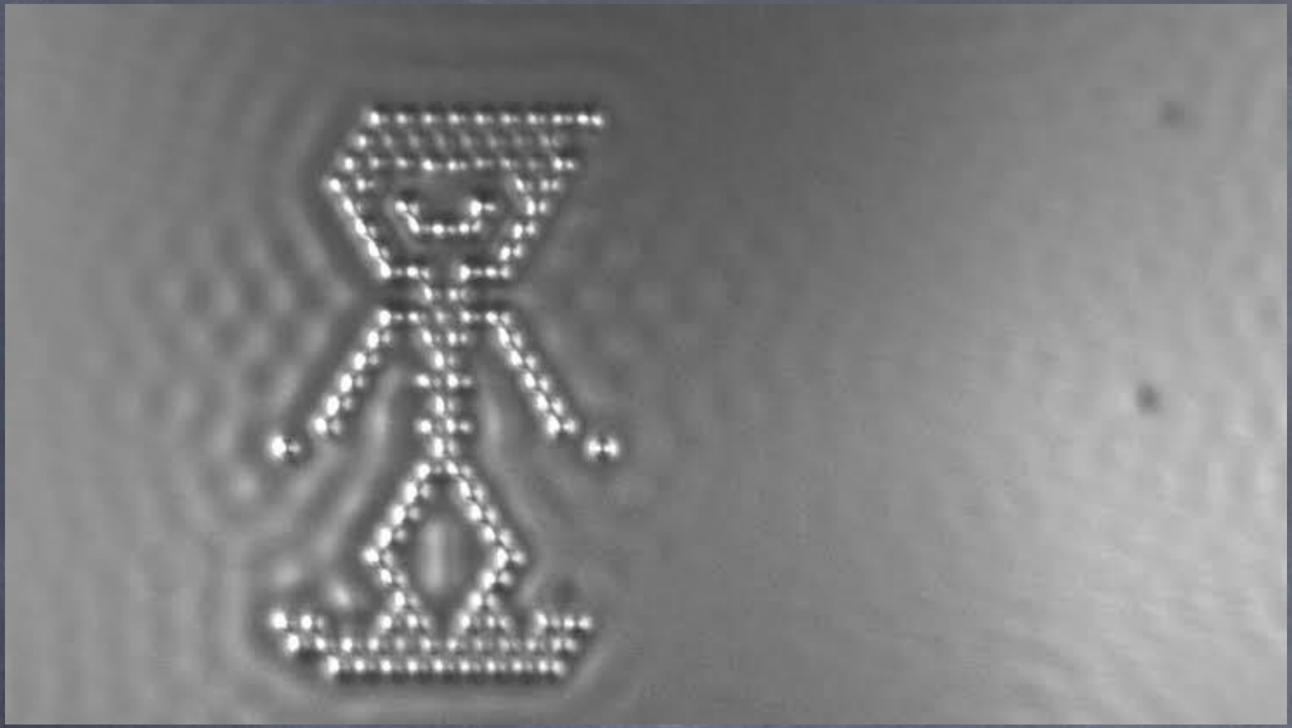
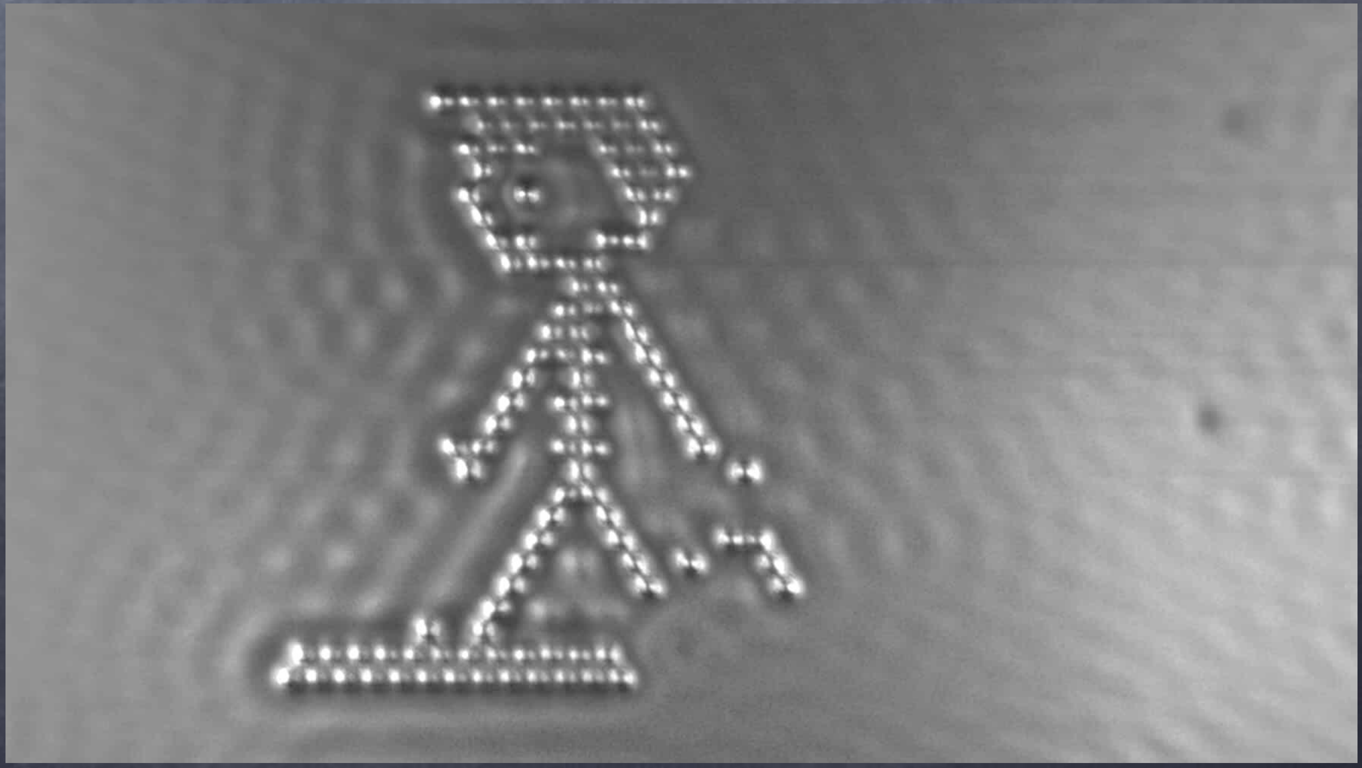


IBM Scan Tunneling Microscope




IBM


A BOY AND
HIS ATOM
THE WORLD'S SMALLEST MOVIE

Tunneling Diodes

- Developed in 1958 by Leona Esaki at Sony
- Tunneling diodes are designed with a heavily doped p-n junction that is only 10 nm wide
- At low voltages, the p and n states are aligned, allowing electrons to tunnel across the gap
- As voltage increases these states become more misaligned and fewer electrons flow
- This negative resistance region allows the diode to operate at very high frequencies, well into the Gigahertz range

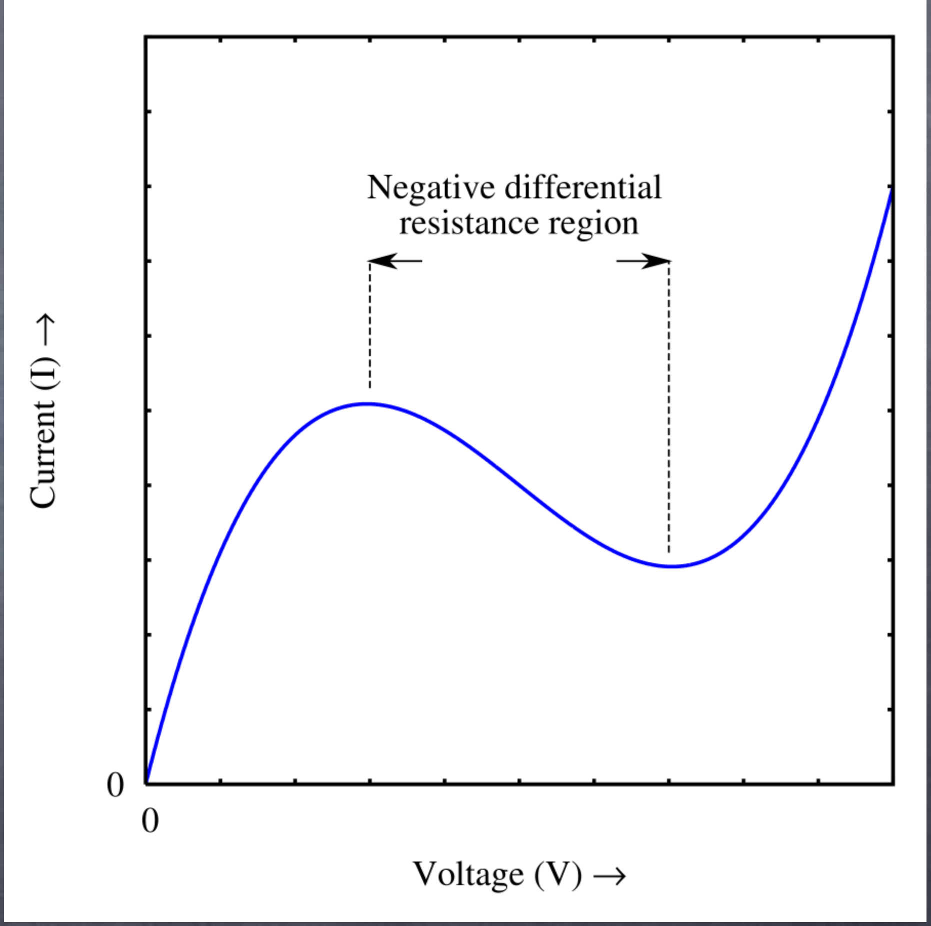


Image courtesy of Wikipedia

Thank You