Manipulating electron and photon waves

- An electron wave packet can be manipulated by squeezing it into a quantum box with a size comparable to the electron wavelength (≈ nanometer).
- The wave packet determines the behavior of the electron, for example in an electronic device.
- Such “engineered” electron wave packets make useful devices, such as the quantum well laser. Every DVD player contains a quantum well laser.
A quantum box

- An electron wave with wavelength $\lambda = 2L$ fits into the box.
- $\lambda$ determines the momentum: $p = \frac{h}{\lambda} = \frac{h}{2L}$
- $p$ determines the kinetic energy: $E_{\text{kin}} = \frac{1}{2} m_e v^2$
  $= \frac{1}{2} p^2 / m_e$
  $= \frac{h^2}{8 m_e L^2}$

A smaller box requires higher energy.
Nanocrystals

Crystal size determines the color

Blue when small  ( small $\lambda_{\text{elec}} \Rightarrow$ large $E_{\text{elec}} \Rightarrow$ large $E_{\text{phot}} \Rightarrow$ small $\lambda_{\text{phot}}$ )
A leaky quantum box

• When the walls of a quantum box get too thin, an electron wave packet is able to leak out.

• This process of magically penetrating the wall of a box is called tunneling.

• It is like getting across a wall by digging a tunnel through the wall instead of climbing over it.
Tunneling between leaky boxes

- When another leaky box is brought nearby, the electron may disappear from one box and appear in the other!
- That works only if the wall is just a few atoms wide.
- A solid acts like a box for electrons, vacuum like a wall.
Changing the wall thickness

The tunneling probability decreases rapidly for thicker walls.
Scanning Tunneling Microscope (STM)

• Electrons tunnel from the yellow surface atoms to the blue atoms at the tip, even though they don’t have enough energy to get across the vacuum in between (which acts like a wall).

• Very sensitive to height! The tunneling probability changes by a factor of 100 when the tip moves by an atom diameter.

• While the tip scans across the surface, its height is recorded.
Quantum Corral

- 48 iron atoms are assembled into a circular ring.
- The ripples inside the ring are electron waves.
A ‘quantum corral’ is assembled by moving individual iron atoms on a copper surface with the tip of a STM.

As the circle of atoms becomes more complete, electron waves at the surface become more orderly.

This shows how the behavior of electrons can be manipulated by a nanometer-size pattern (here 14 nm diameter).
Playing with atoms

Kanji character for atom (lit. original child)

Carbon Monoxide man