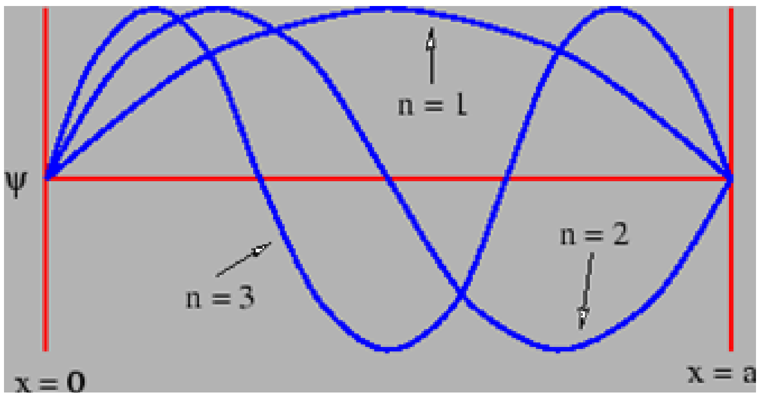
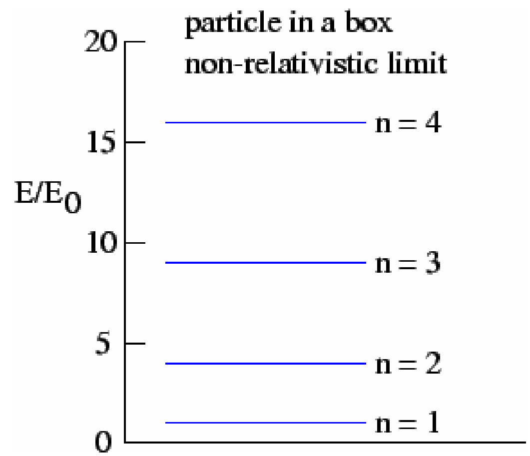
Particle in the Box: 1D





$$\psi(x) = A\sin(\pi x / a)$$

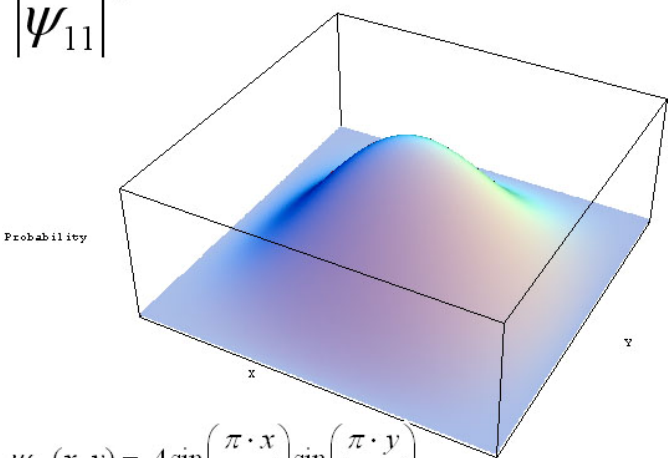
Wave-nature of particle:

1. Lowest energy state varies - has momentum – energy – zero point energy
2. The probability is zero at places: particle bundled in locations ~ atom orbits
3. States have specific numbers associated with them: n=1,2,3.
   n=number of nodes+1.

“quantum numbers”

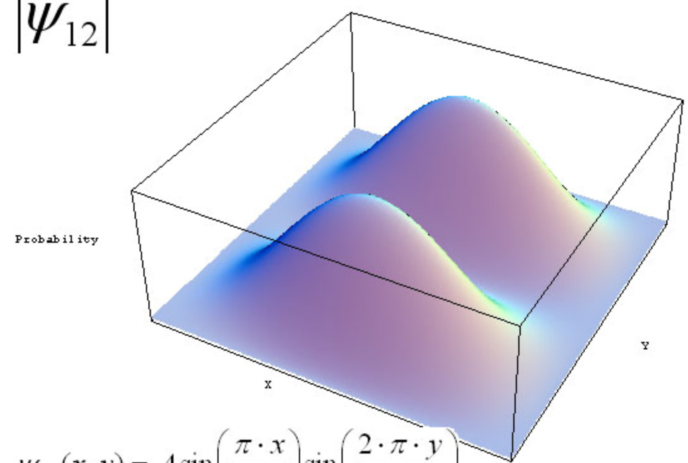
Particle in the Box: 2D

$|\psi_{11}|^2$



$\psi_{11}(x,y) = A\sin\left(\frac{\pi \cdot x}{a}\right)\sin\left(\frac{\pi \cdot y}{a}\right)$

$|\psi_{12}|^2$



$\psi_{12}(x,y) = A\sin\left(\frac{\pi \cdot x}{a}\right)\sin\left(\frac{2 \cdot \pi \cdot y}{a}\right)$

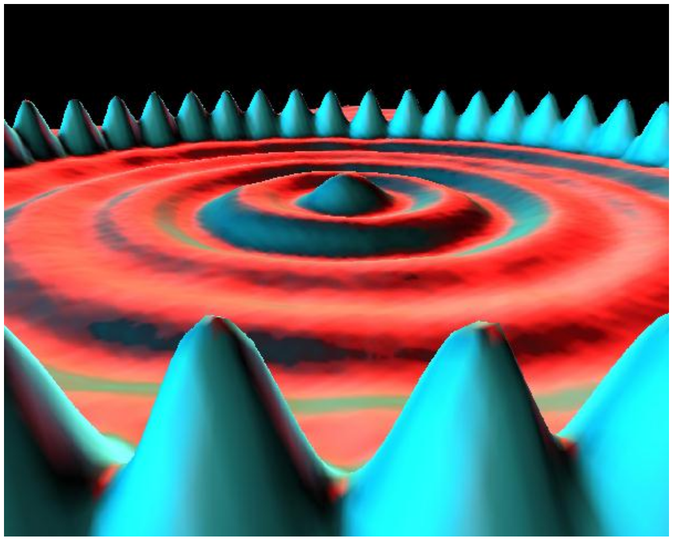
Nodes can be in either direction: two quantum numbers

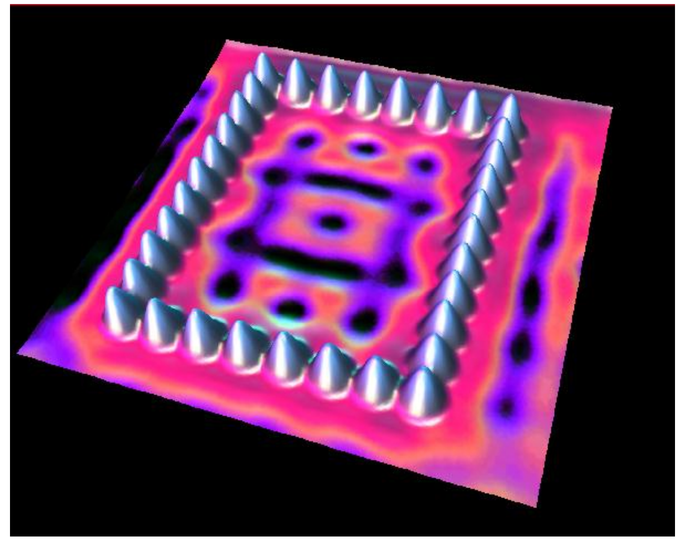
No nodes in either direction (1,1) state

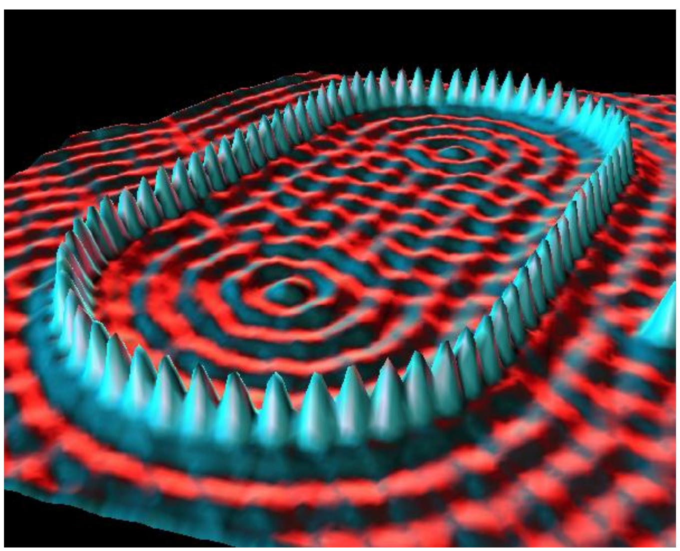
Node in the y direction: (1:2) state

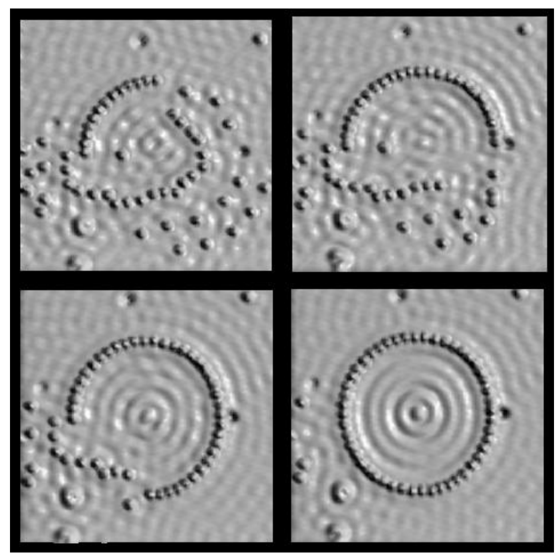
Node could be in x direction, too. Same wave, just rotated: energy same
E(1:2)=E(2:1)
The (2:1) state is "**degenerate**"
The degree of degeneracy is twofold

Can we see Quantum Waves?





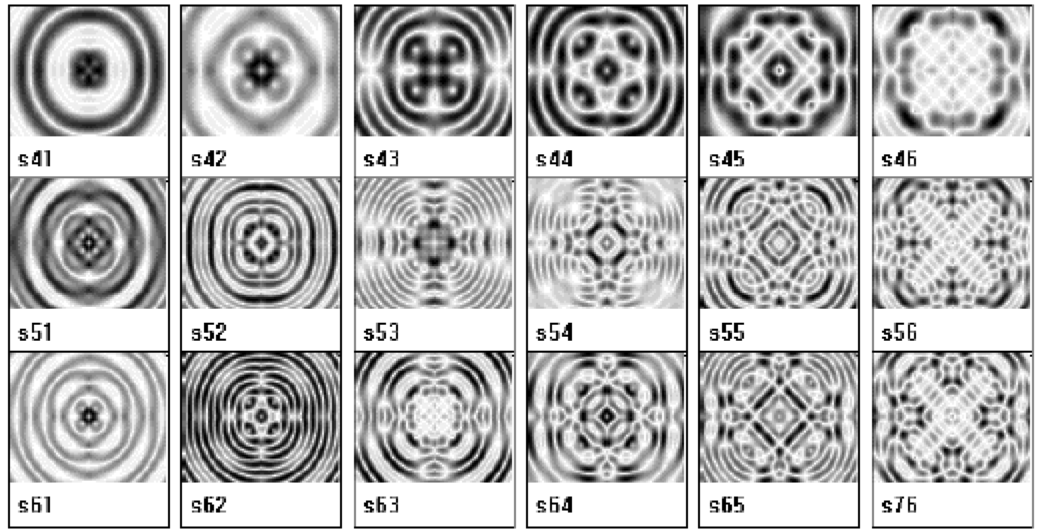




D. Eigler:
Iron on
Copper
surfaces

Higher Dimensions: Complicated Patterns

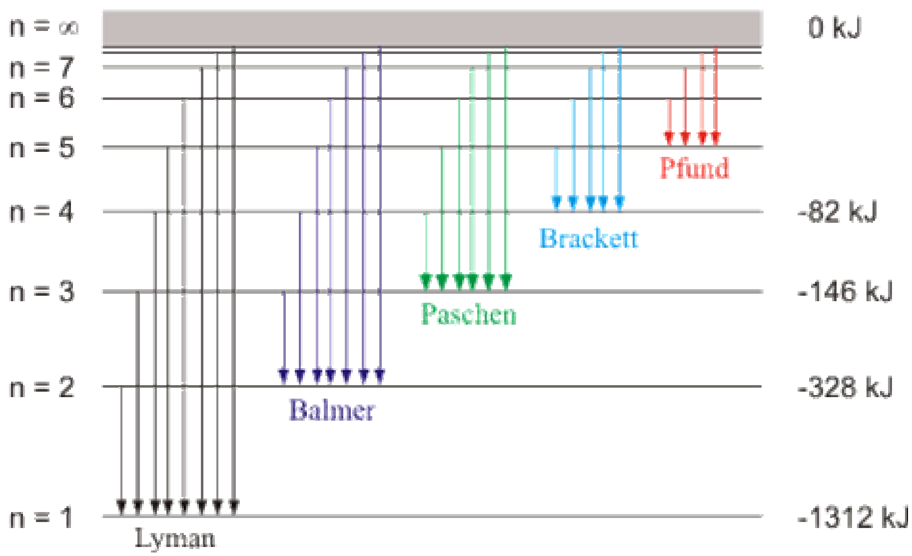
violin



drum

Fun

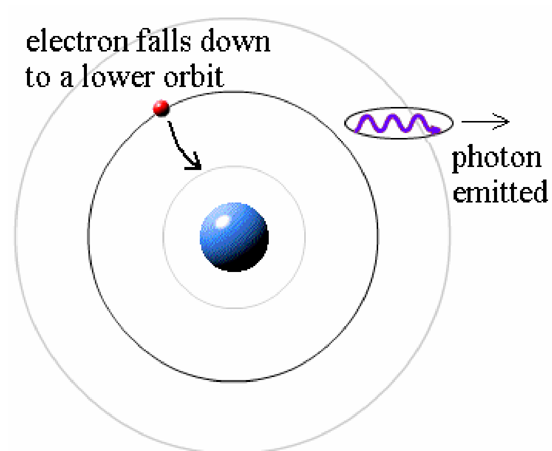
Schroedinger and the Hydrogen Atom



0 eV

-13.6 eV

UV visible



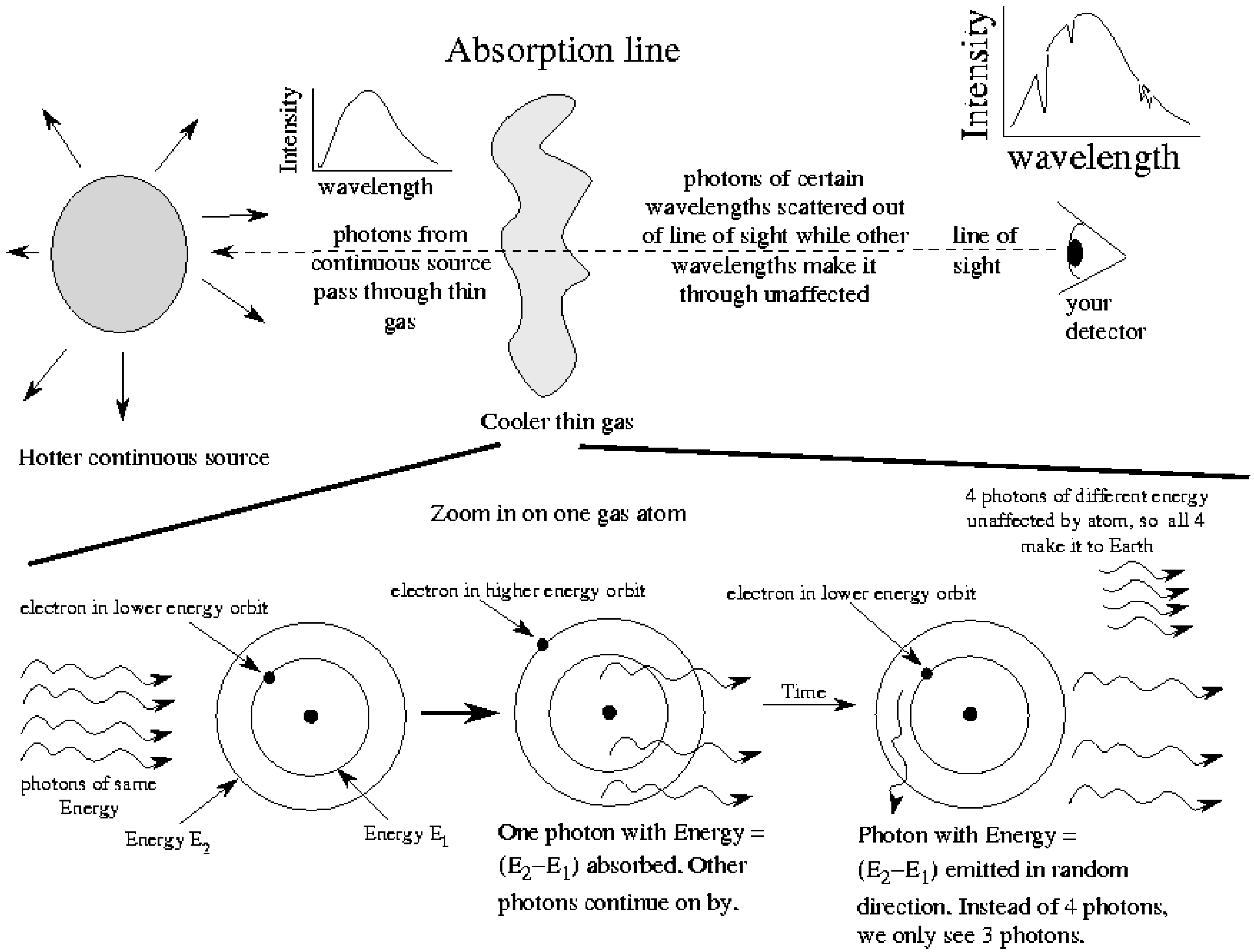
$$f = c/\lambda$$

$$\frac{1}{\lambda} = \tilde{R}\left(\frac{1}{m^2} - \frac{1}{n^2}\right)$$

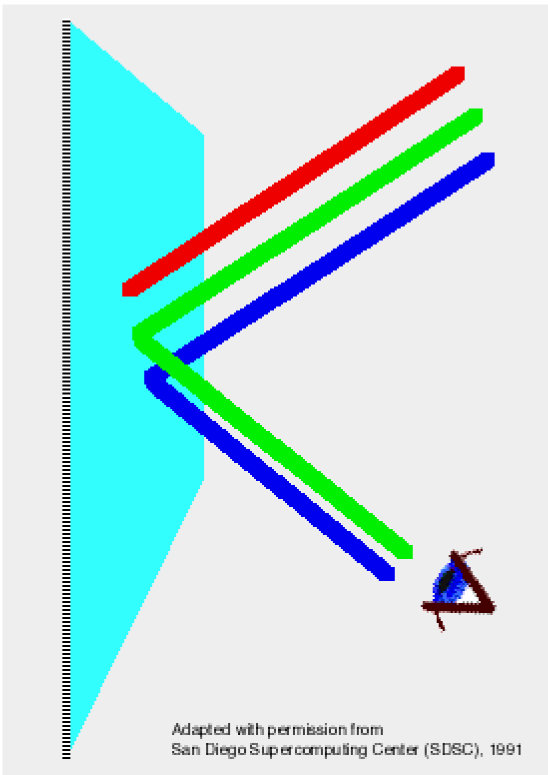
E = -R/n²

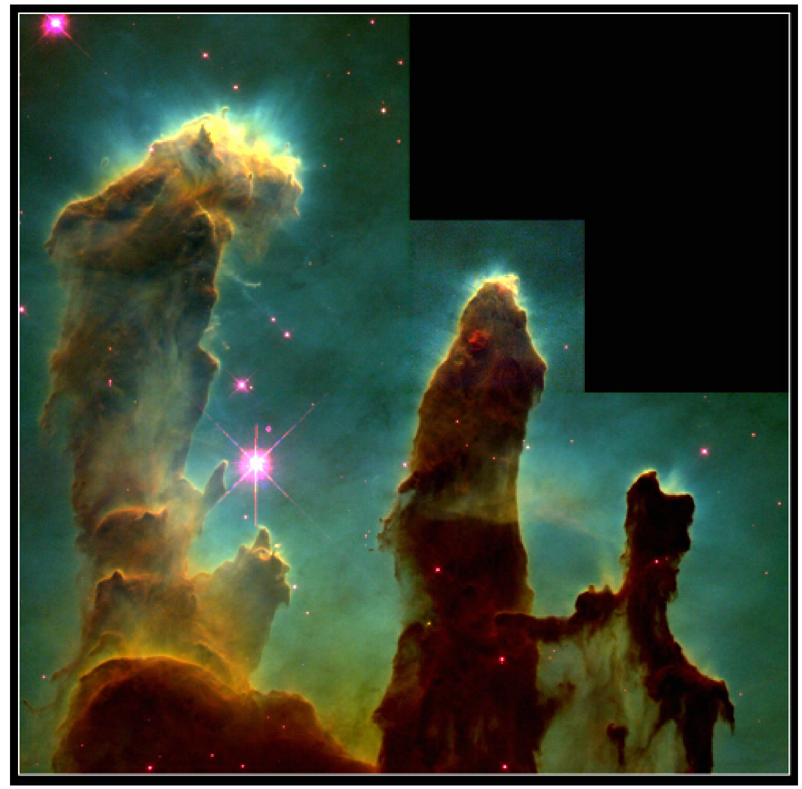
n: integer
R: "Rydberg", 13.6eV

Absorption I.



Absorption II: the Origin on Color

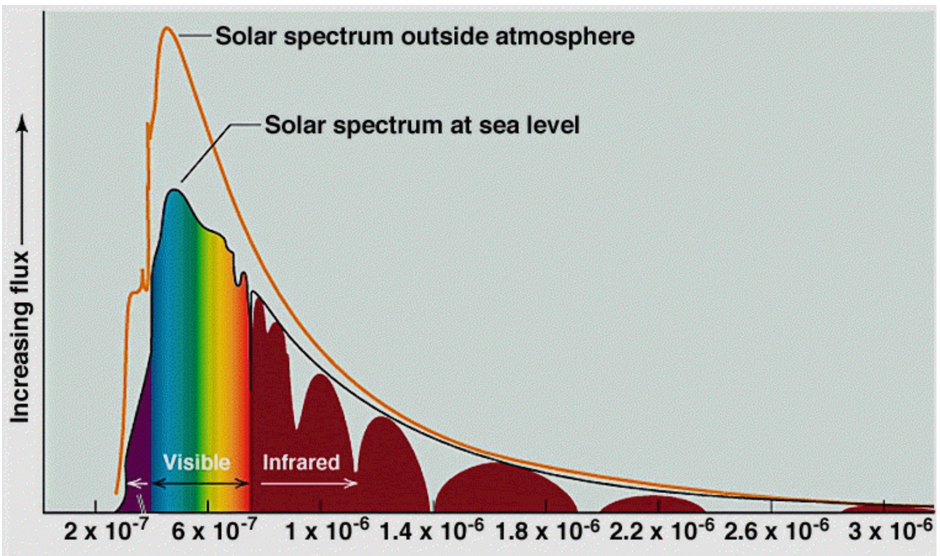


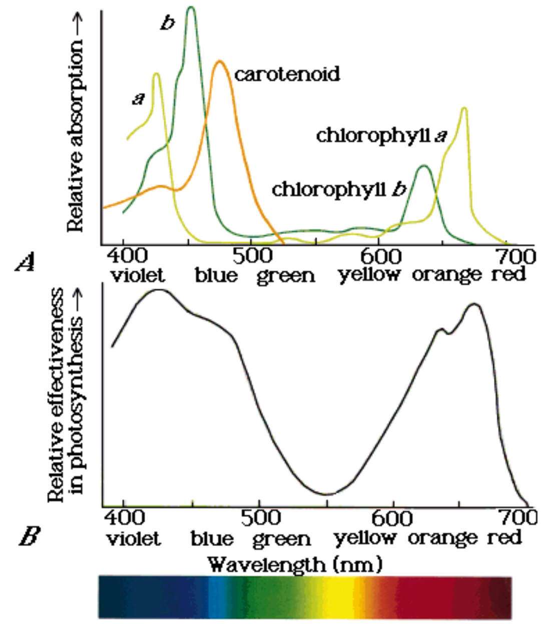


- Sunlight has 3 main components RGB
- Red is absorbed, if for atoms E(f)-E(i)=h f(red)
- Remaining light has bluish/greenish color

- Incoming light is UV
- Electron gets highly excited
- Cascades down through several transitions, emitting visible light

Absorption III.: Why are Plants Green?





Maximum of solar intensity: in green

So plants should absorb green most efficiently

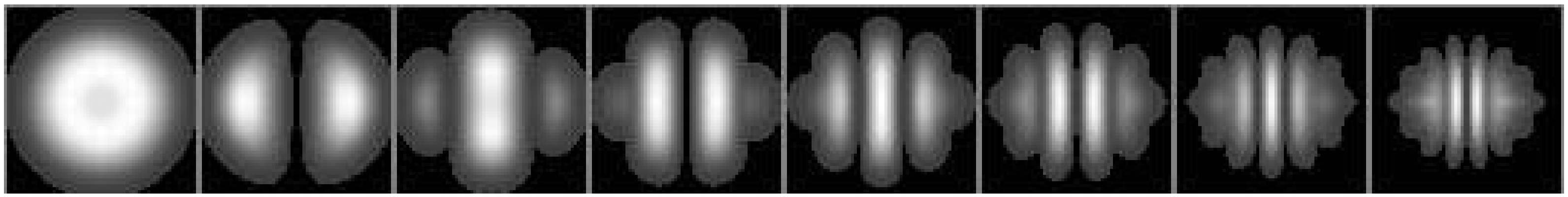
But then they should be red, which they are not

Plants did not find **one** chlorophill which absorbs in green

So instead they use **two** molecules, absorbing in blue and red:

The reflected light is green

Wavefunctions in Hydrogen Atom



n = 1 2 3 4
name: s p d f

Higher n states are degenerate: several states have same energy
They differ in another quantity: their angular momentum

$$L = r \times p$$

L: angular momentum;
p: regular momentum p=mv;
r: distance of electron from nucleus

Wavefunctions of Hydrogen Atom

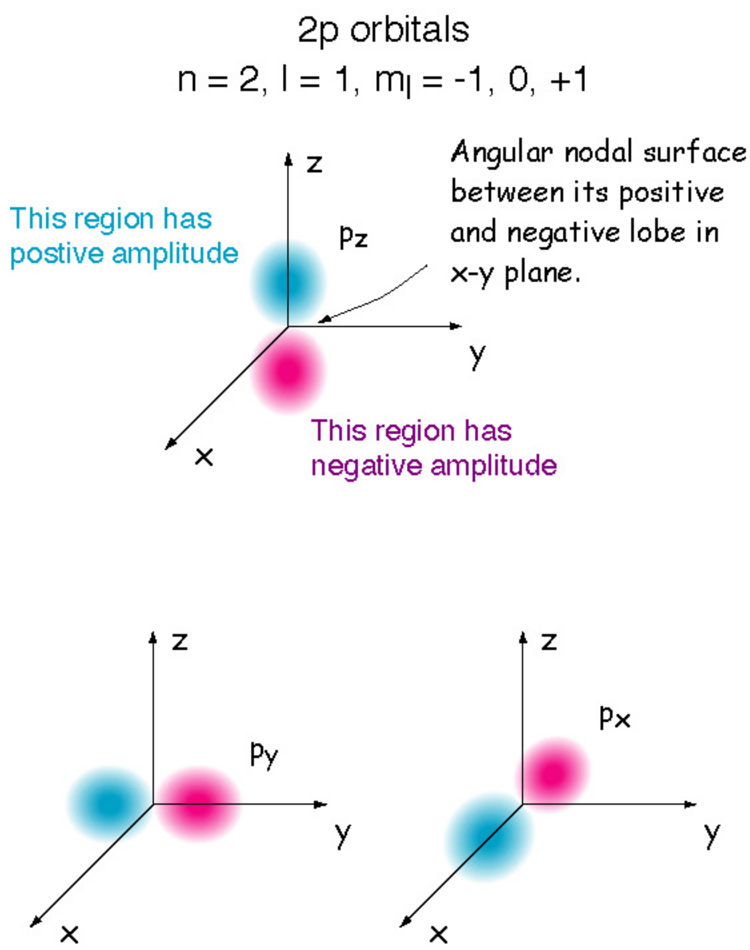
n: measures energy
l: angular momentum (~# of nodal planes)
m: direction of angular momentum

n=1, l=0, m=0 — s: *non-degenerate**

n=2, l=0, m=0
n=2, l=1, m=-1, 0, +1 — *p: 4 fold degenerate*

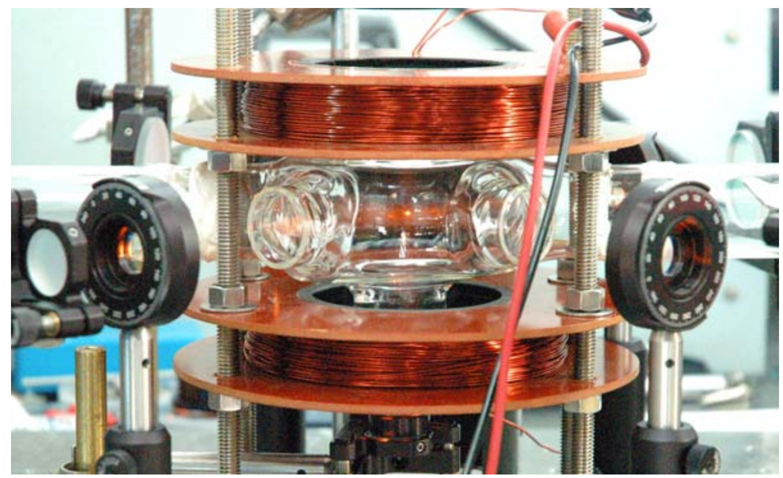
n=3, l=0, m=0
n=3, l=1, m=-1,0,+1 — d: *9 fold degenerate*
n=3, l=2, m=-2,-1,0,1,2

Allowed values: l=0,…,(n-1)
m=-l, …,0, …l



Trapping Particles: Two Generations

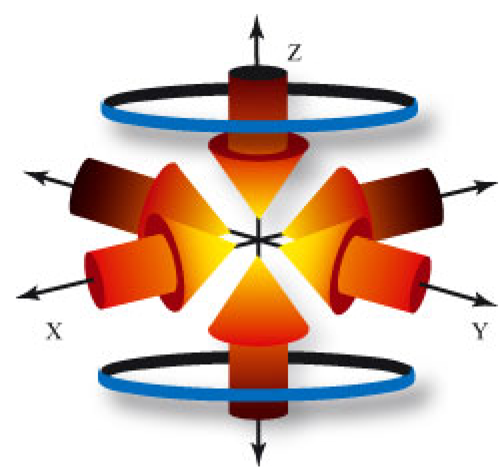
- two negatively charged metal plates
- inhomogeneous magnetic field
- let particles leak out until one is left



Dehmelt: ’73: electron
+Paul: ’79 atom

Nobel 1989

Six laser beams
Inhomogeneous magnetic field
Very cold

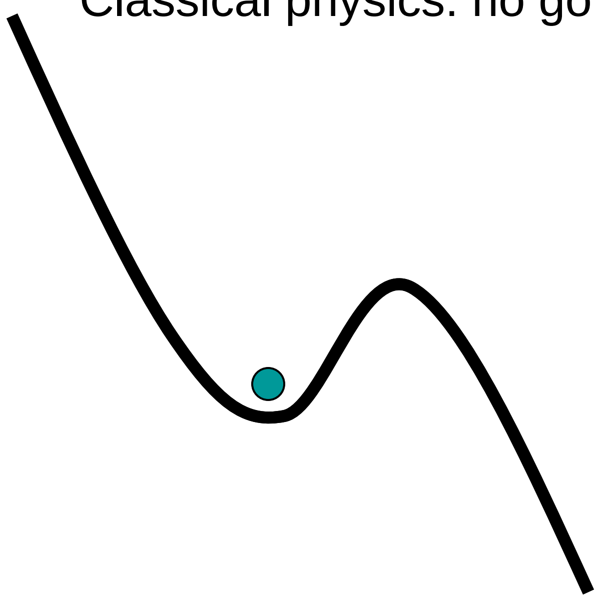


Steve Chu (Lawrence Berkeley Lab)
Nobel 1997

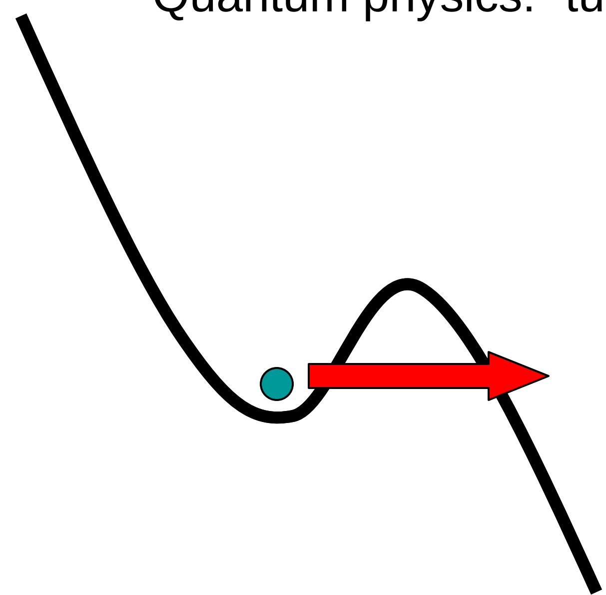
Quantum Tunneling I.

In quantum mechanics various laws of nature can be violated (a little bit) because of the uncertainty relation.

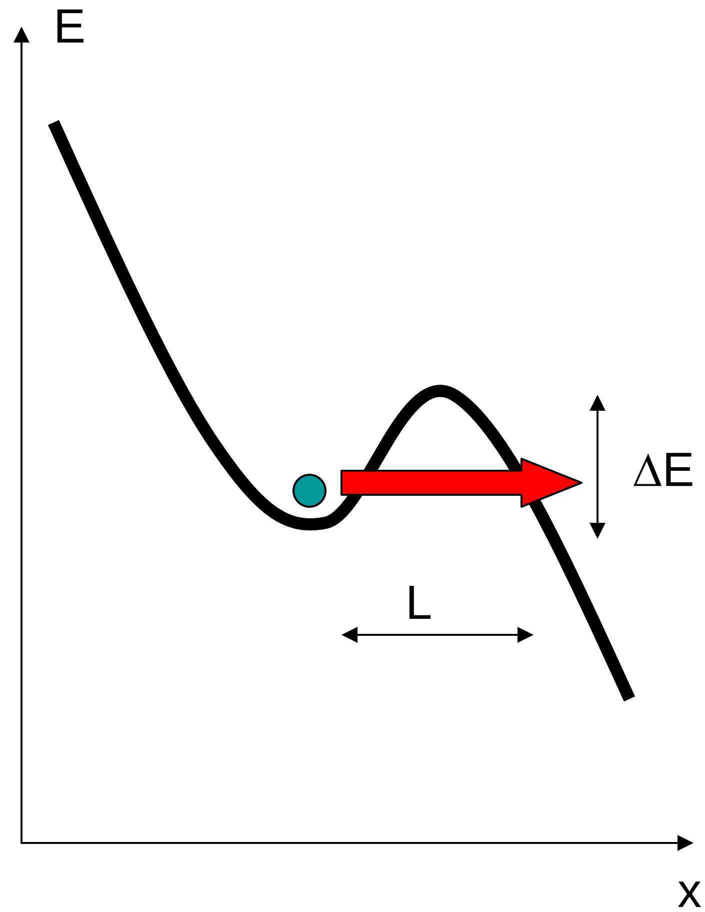
Classical physics: no go



Quantum physics: “tunneling”



Quantum Tunneling II.



1. Location is uncertain: L~Δx
   with a very small probability the particle maybe outside the well

2. Other (equivalent) uncertainty relation:

$$\Delta E\ \Delta t \sim h$$

For a short Δt time you can “borrow” an energy ΔE, “violating” the law of energy conservation.

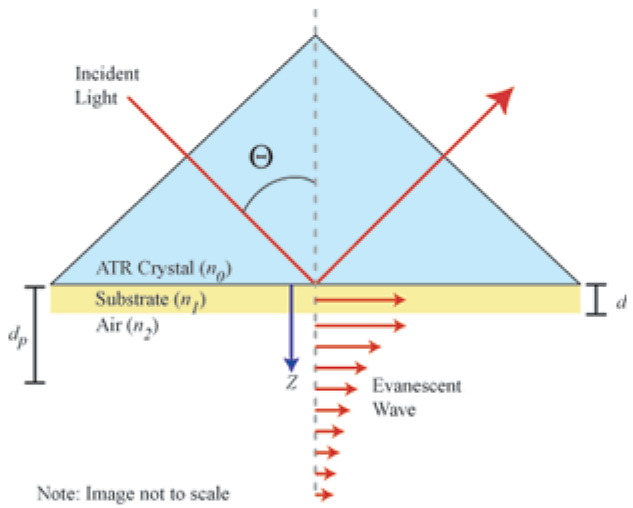
Of course all conservation laws remain valid for averages and “long” times

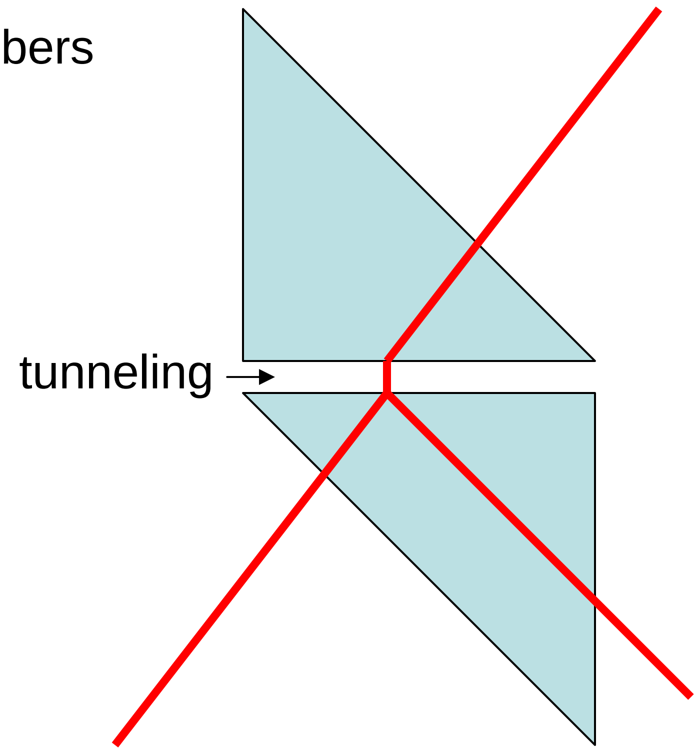
Light Tunneling I.

Classical: Total reflection in prism

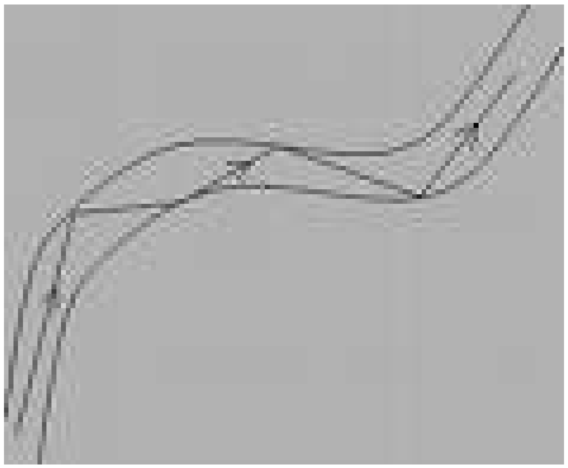
Quantum: Small percentage tunnels out of prism

Primary cause of loss of signal in optical fibers

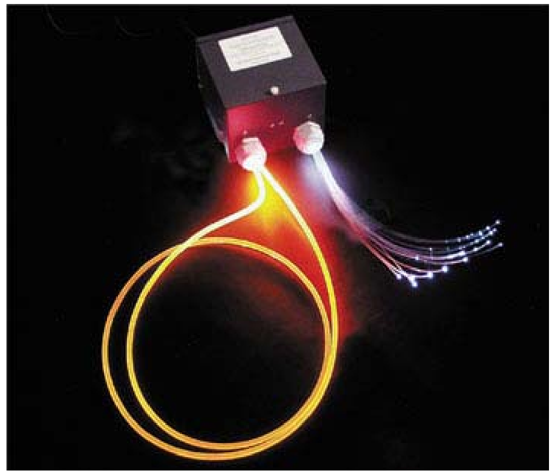




Light Tunneling II.



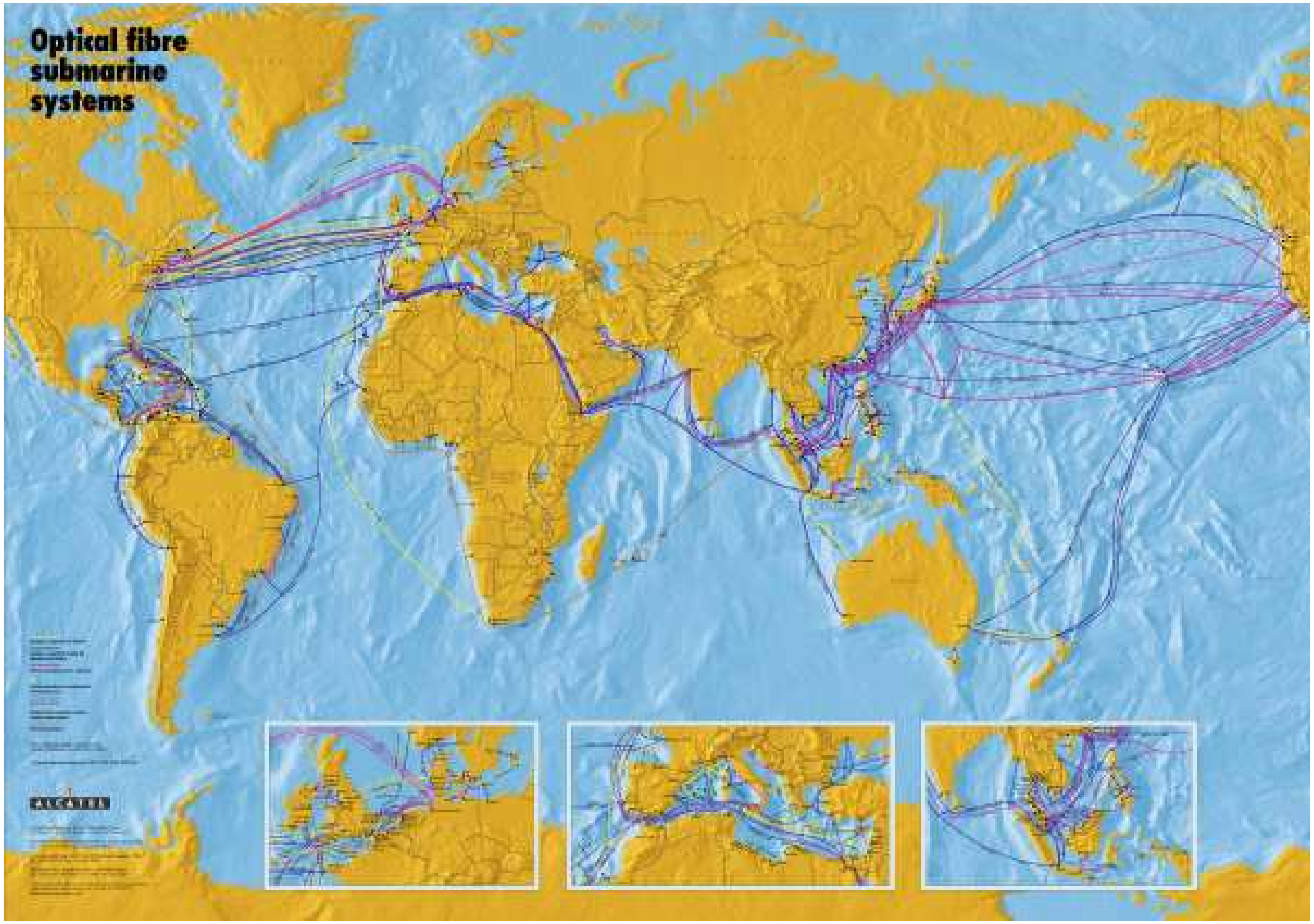
Light propagates in fiber:
- huge number of internal reflections
- even small loss is significant



Industrial optical cables:
- minimize tunneling

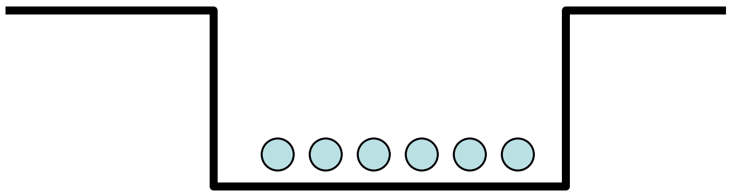
Art:
- tunneled light makes it beautiful

Light Tunneling III.: Optical Submarine Cables

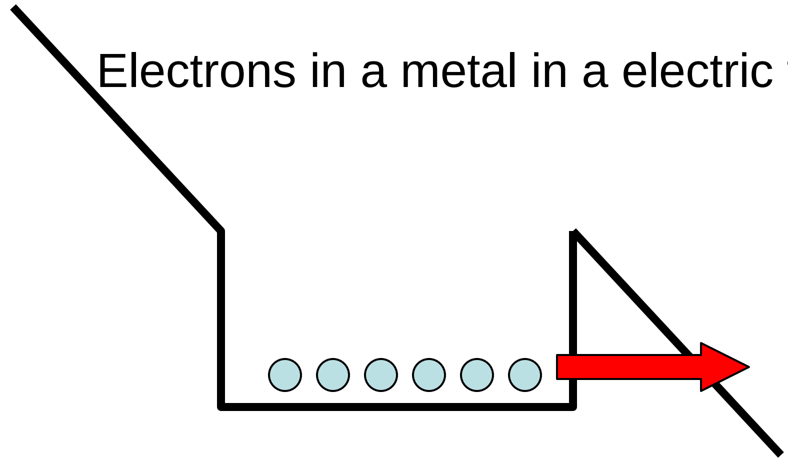


Electron Tunneling I.

Electrons in a metal



Electrons in a metal in a electric field



Gerd Binnig:

1. let us use electrons to image the surface of metals
2. place an electron collector close enough to metal
3. put large enough electric field between collector and metal
4. electrons will tunnel out
5. if there is a bump on the surface: more electrons tunnel out
6. this gives more current.

Increase in tunneling current = bump on surface

Scanning Tunneling Microscope I.

Questions:

1. How close do we have to hold the collector? A few atomic diameters $d=10^{-9}$m
2. How precisely do we have to hold it there? Variations have to be $\Delta d \ll 10^{-9}$m
3. This is still only a point. How to map surface? Move/scan collector

All very hard

Like Flying a 747 an Inch from the Ground