Great Idea:
At the subatomic scale, everything is quantized. Any measurement at that scale significantly alters the object being measured.
The term "laser" originated as an acronym for Light Amplification by Stimulated Emission of Radiation. The emitted laser light is notable for its high degree of spatial and temporal coherence.

\[ E_2 - E_1 = \Delta E = h\nu \]
How is Laser light produced
Summary

• The World of the Very Small
• Probabilities
• Wave-Particle Duality
• Wave-Particle Duality and the Bohr Atom
Measurement and Observation in the Quantum World

• 3 components to measurement
  – Sample
  – Source of energy
  – Detector

• **Quantum world**
  – *Measurement alters object*
The Heisenberg Uncertainty Principle

• Uncertainty Principle:
  – At quantum scale, measurement alters object

• Cannot know position and velocity

• Equation:
  \[ \Delta x \times \Delta v \geq \frac{h}{m} \]
The Heisenberg Uncertainty Principle – cont.

• Compare large versus small objects
  – Small uncertainty with large object
  – Large uncertainty with small object

If light has both particle and wave characteristics/properties...
Why should not a particle with known mass have both properties (wave and particle)?

Momentum = mass × velocity

\[ \nu = \lambda f \]

Wavelength of any body (stars, animals, etc) = \( \frac{h}{\text{momentum}} = \frac{h}{(\text{mass} \times \text{velocity})} \)

At normal mass and velocity...wavelength is small.... too small to see interference patterns
Example: A bullet that weighs 20 g is traveling at 330 m/s

What is the wavelength?

Wavelength of any body (stars, animals, etc) = $h$/momentum = $h/(\text{mass} \times \text{velocity})$

Wavelength of bullet = $h/(0.020 \text{ kg} \times 330 \text{ m/s})$

$= 6.6 \times 10^{-34} \text{ J.s}/(0.020 \text{ kg} \times 330 \text{ m/s})$

$= 10^{-34} \text{ m}$

Can we measure it?

$\Delta x \times \Delta v \geq \frac{h}{m}$
Example:
What about an electron traveling at 2% of the speed of light...

What is the wavelength?
c=3×10^8 m/s  2% of the speed of light gives v=6×10^6 m/s
mass of an electron = 9.10938188 × 10^-31 kilograms

Wavelength of any body (stars, animals, etc) = h/momentum = h/(mass x velocity)

Wavelength of electron = h/(9.10938188 × 10^-31 kgs x 6x10^6 m/s)
= 6.6 × 10^{-34} J.s/(9.10938188 × 10^{-31} kgs x 6x10^6 m/s)
=10^{-10} m

Can we measure it?
Probabilities
Probabilities

• Newtonian view
  – Determine velocity and position

• Quantum view
  – Cannot determine velocity and position
  – Use probability
Position of the "Quantum Baseball"
Wave Particle Duality
The Double-Slit Test

- Energy
  - Particles
  - Waves
- Photons
  - Emit photon
  - Flood of photons
Wave or Particle

(a) Particle gun (shooting baseballs)

(b) Wave source

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Double-Slit - cont.

• Single photon over time
• Results depend on experimental design
• Visualizing
  – Not wave or particle
Electrons Moving through a Two-Slit Barrier

(a) Moving electrons through a double slit barrier. (b) Film showing the interference pattern created by the electrons. (c) Close-up of the film showing individual electron spots. (d) Another angle of the film.

Technology

• The photoelectric effect
  – Role in the history of quantum mechanics
• Digital camera
• CAT scan
Wave-Particle Duality and the Bohr Atom
Wave-Particle Duality and the Bohr Atom

• Speed and wavelength
  – Faster speed = shorter wavelength

• Particle
  – Precise velocity = stable orbit

• Wave
  – Uniform vibration at certain frequencies

• Combine wave and particle?
  – Only orbits allowed are those where both particle and wave work
Standing Wave of an Electron in Orbit

Nucleus

$r$
Quantum Weirdness

• Richard Feynmann - “I can safely say that nobody understands quantum mechanics. ... Do not keep saying to yourself, ‘But how can it be like that?’ ... Nobody knows how it can be like that.”

• Be Careful!
  – Quantum mechanics is still a marvelous and necessary tool for understanding the quantum world
Quantum Entanglement

• Quantum entanglement
  – Dice

• Photons emitted at same time
  – Despite distance, remain entangled

• Quantum teleportation
Quantum Teleportation

Bob sends a photon to Alice

Bob keeps a photon

Alice

Entangled photons

Bob

Interaction and measurement

Information of interaction

Reconstructs signal photon

Signal photon

Photons destroyed

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Introduction to Chapter 7

Time dilation and space contraction

Relativity
http://youtu.be/LHPqhTY6dh0

Time Dilation and Space Contraction
http://youtu.be/xvZfx7iwq94