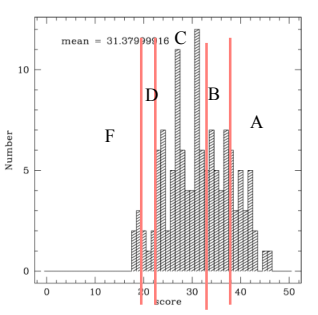
Test results

Grades posted online

If you are not properly registered then come see me for your grade



Clicker Question:

Power is transmitted at very high voltages so that the corresponding current is:

A: also high to deliver appreciable power to distant places

B: low so that overheating of the wires and other energy losses are minimized

C: identically zero

D: None of the above

Clicker Question:

A standing wave occurs when:

A: two waves overlap

B: the amplitude of a wave exceeds its wavelength

C: a wave is reflected onto itself

D: the speed of the wave is zero or near zero

Clicker Question:

Given that Jupiter orbits at about 5 times further from the Sun than the Earth, how does the intensity of the sunlight compare at Jupiter compared to the intensity at the Earth (where it is 1250 watts/square meter)?:

A: 2500 watts/square meter

B: 250 watts/square meter

C: 125 watts/square meter

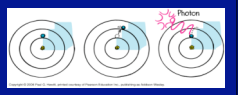
D: 50 watts/square meter

Quantum Mechanics

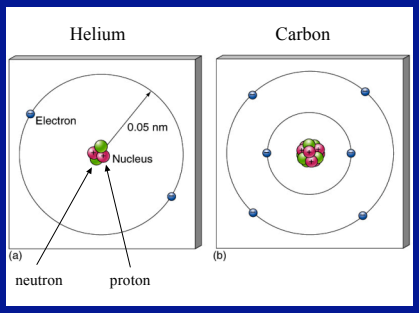
- Physics on the scale of individual atoms and photons

A Brief Introduction to Quantum Physics

- At the microscopic level, allowed energies are discrete or quantized
  - Not all energies are possible
    - Fair Analogy
- Photon – discrete packet of energy
  - Smallest unit of energy that can exist as EM radiation at a certain frequency: $E=hf$
    - *Planck's constant:* $h = 6.6 \times 10^{-34}$ *J·s*
      - *Sets a lower limit on the energy transferred in any interaction*



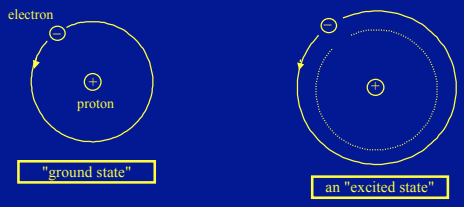
Atoms



Atoms have equal positive and negative charge. Each element has its own allowed energy levels and thus its own spectrum.

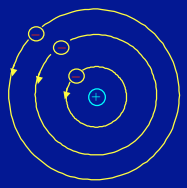
The Nature of Atoms

The Bohr model of the Hydrogen atom:



Ground state is the lowest energy state. Atom must gain energy to move to an excited state. It must absorb a photon or collide with another atom.

But, only certain energies (or orbits) are allowed:



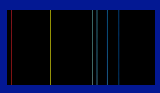
a few energy levels of H atom

The atom can only absorb photons with exactly the right energy to boost the electron to one of its higher levels.

(photon energy α frequency)

Types of Spectra

2. "Emission line" spectrum - bright at specific wavelengths only.



3. Continuous spectrum with "absorption lines": bright over a broad range of wavelengths with a few dark lines.

Wave-Particle Duality

- Light behaves sometimes like a wave and sometimes like a particle
  - What are some properties of waves?
  - What are some properties of particles?

Wave-Particle Duality

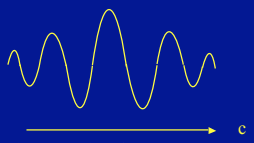
- Light behaves sometimes like a wave and sometimes like a particle
  - Wave properties
    - Refraction, Interference, Diffraction
  - Particle properties
    - Spacetime location (occupies a definite position at a definite time)
    - Inertia
  - Waves spread out in space and time
    - No identifiable "position"
  - Particles have definite locations and travel through space inertially

Wave-Particle Duality (cont.)

- Ex. Image produced by a camera
  - Light waves spread out, refract as they pass through the lens, and are focused on the film
  - Photons strike photographic emulsion exposing the film grain by grain

The Particle Nature of Light

On microscopic scales (scale of atoms), light travels as individual packets of energy, called photons.



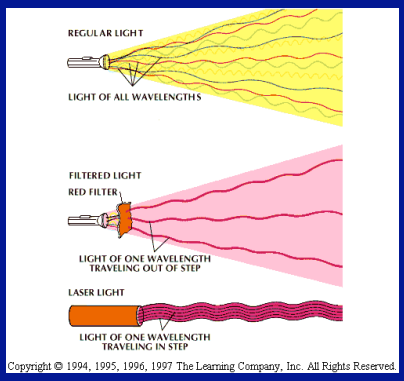
photon energy is proportional to radiation frequency:

$E \alpha \nu$ (or $E \alpha \frac{1}{\lambda}$)

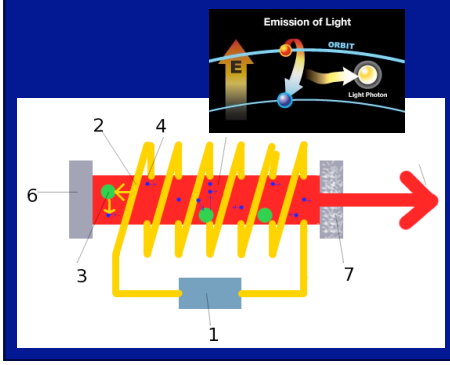
example: ultraviolet photons are more harmful than visible photons.

LASERS

Invented in 1958 by Gordon Gould



Light Amplification by Stimulated Electromagnetic Radiation



Clicker Question:

The energy of a photon is proportional to its:

A: frequency

B: wavelength

C: period

D: speed

Clicker Question:

Which of the following a property of waves:

A: clearly identifiable position

B: travel in straight lines

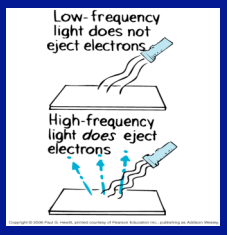
C: carry energy

D: interference

Photoelectric Effect

- Light can knock electrons off of metals
  - Demonstrates particle-like nature of light
    - Electrons ejected as soon as light is turned on
    - Occurs for blue light, but not for red
    - Rate depends on brightness
    - Electron energy depends on frequency

DEMO

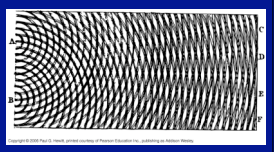


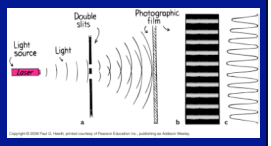
Einstein – Light is also quantized, with energy proportional to frequency.

Photon absorption is "all-or-nothing".

The Double-Slit Experiment

- Two stones dropped in pond => wave interference (Top)
- Similar to when light is shone through a double-slit (Bottom)
  - Bands caused by interference
- What if instead bullets were fired at the double-slit?

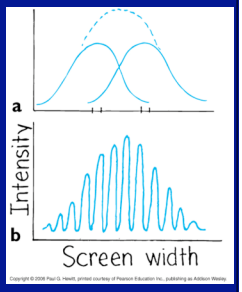




(Shockwave_Demo) (Web Link)

The Double-Slit and Photons

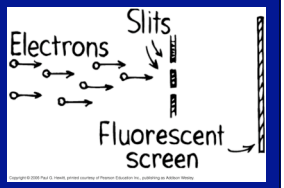
- If bullets are fired, solid curves in (a) describe holes in wall
  - Dashed line => both slits open
- If one photon at a time shown through only one slit => build up one of the solid curves in (a), but
  - If both slits are open, over time light yields curve (b)!
    - Each photon seems to pass through both slits at once and interfere with itself!



(Shockwave Demo) (Web Link)

Massive Particles

- What if you fired a beam of massive particles like electrons at a double-slit.
  - Would you still observe an interference pattern?



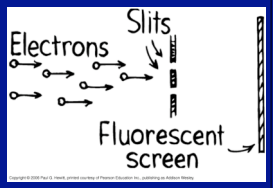
DEMO

Massive Particles

- Louis de Broglie - massive particles have an associated wavelength:

$$\text{Wavelength} = \frac{h}{\text{momentum}}$$

  - Ordinary objects: wavelengths are negligible
  - The wave nature of material objects has been verified for many subatomic particles



Electrons entering the apparatus one at a time exhibit both wave and particle properties, just like their massless counterparts the photons.

The Uncertainty Principle

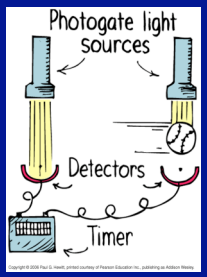
- Quantum processes
  - Random "acts of creation"
  - Measurement disturbs the system in an unpredictable way!
    - Negligible effect for baseball, but important for subatomic particles

$$\Delta p \Delta x \geq h/2\pi$$

Δp – uncertainty in momentum

Δx – uncertainty in position

    - Holds for all interactions
    - The more we know about one, the less we can know about the other



A device to measure the position of an object will change the object's momentum.

Measurement

- Measuring (or obtaining information about) any object requires some type of interaction with the object.
  - What does this imply about measurements made on subatomic particles like electrons?
  - How is the situation different when the object being studied is large, e.g. a baseball?

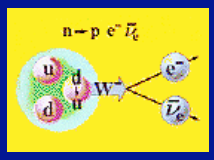
Demo: Schrodinger's Cat

- Ingredients: Black Box, Cat, Radioactive Isotope, Hammer, Poison Vial, Geiger Counter
- Recipe:
  - Place all ingredients in black box.
  - Ensure that hammer will shatter vial only if Geiger counter detects a particle.
  - Close lid and wait for time = half-life
- End Product – cat that is simultaneously dead and alive (until you look!)
  - Demonstrates difficulty in identifying dividing line between classical and quantum realms!

Quantum fluctuations in the Vacuum

$\Delta E \Delta t \approx \frac{h}{2\pi}$ Another form of the Uncertainty Principle

sketch



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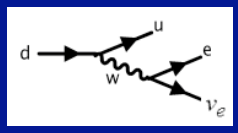
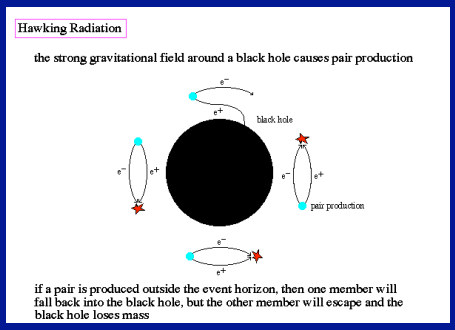
Feynman Diagram



A neutron decays into a proton, electron and neutrino via a mediating virtual W boson

Hawking Radiation

Black holes are not completely black!



Hawking radiation continued:

Effective Temperature ~ 1/mass so big black holes last for a very long time >> current age of the Universe

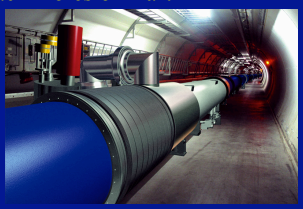
After 10^{21} y a solar mass black hole will evaporate away

Final stage of black hole radiation is explosive with 10^6 kg of mass converted into energy

After 10^{100} y, even the most massive black holes are gone.

Making Black Holes on Earth

Large Hadron Collider (LHC)



Clicker Question:

A hypothetical atom has 4 energy states. Assuming all transitions are possible, how many spectral lines can this atom produce?

A: 2

B: 4

C: 6

D: 8

Clicker Question:

Heisenberg's uncertainty principle states that if we know an object's position exactly then we can't know its:

A: location

B: velocity

C: trajectory

D: destiny