Now … something else adding to the complication, debate and confusion …

Blackbody Radiation

and

The Photoelectric Effect

What are these?

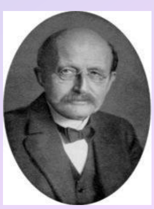
How do we explain them?

Blackbody Radiation: What is it?

- Blackbody – an ideal body that absorbs/emits all frequencies
- When solid bodies are heated, temperature increases, the amount of radiation increases
- Light of a certain energy is emitted as temperature increases   Red - White - Blue
- This radiation is caused by the oscillation of electrons

Blackbody Radiation: How do we explain it?

- Studied by Max Planck (gets the Nobel Prize)
- Determines that the energy is absorbed/emitted in whole # multiples of a *very* small quantity of energy
- He called this amount a "quanta" of energy

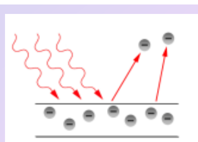


Max Planck
Nobel Prize in Physics, 1918

- It's the smallest amount of energy that electromagnetic radiation can emit/absorb
- Planck's Law $E = h\nu$

h = 6.63 x 10^{-34} Js
(Planck's constant)

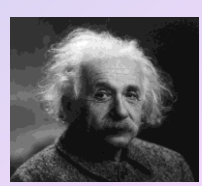
Photoelectric Effect: What is it?



- Electrons are ejected from a metal surface when light or UV radiation shines on it
- High frequency/high energy light (such as blue) can cause electrons to be ejected from the surface of metals
  - even at low intensities (low brightness)
- Low frequency/low energy light (such as red) can't eject any
  - even if the intensity/brightness of the red light is great
- There is a minimum frequency/energy of light necessary for each metal

Photoelectric Effect: How do we explain it?

- Einstein gets the credit (and the Noble Prize)
- With the idea of *quantization* already used by Planck
- Maybe light is like a stream of particles?
- He called these ***photons***
-



Albert Einstein
Nobel Prize in Physics, 1905
for explaining the
Photoelectric Effect

Photons

- Have zero mass and move at the speed of light
- Carry energy and momentum
- Can be destroyed/created when radiation is absorbed/emitted
- Can have particle-like interactions (collisions) with electrons and other particles.
- Brighter light has more photons, but bluer light has higher energy photons
- The energy of a photon is proportional to its frequency $E = h\nu$

Light is a particle.

○ ○ ○ ○ ○ ○

So… is light a wave or a ***particle*** ???

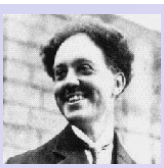
Both.

Wave-Particle Duality

Summary:

- Light moves like a wave
- But transfers energy like a stream of particles

Most significantly, the photoelectric effect, and the photon theory it inspired, crushed the classical wave theory of light. Though no one could deny that light behaved as a wave, after Einstein's first paper, it was undeniable that it was also a particle.



L. de Broglie (1924)

If light has particle properties, does matter have wave properties?

Used Einstein and Planck's equations and proposed that both light and matter obey:

$$\lambda = \frac{h}{mv}$$

λ: wavelength, m; m: mass, kg; v: velocity, m/s

Examples of de Broglie Wavelengths

Substance	Mass(g)	Velocity(m/s)	λ(m)
Slow electron	9×10^{-28}	1.0	7×10^{-4}
Fast electron	9×10^{-28}	5.9×10^{6}	1×10^{-10}
Alpha Particle	6.6×10^{-24}	1.5×10^{7}	7×10^{-15}
1 gram weight	1.0	0.01	7×10^{-29}
Baseball	142	25.0	2×10^{-34}
Earth	6×10^{27}	3×10^{4}	4×10^{-63}

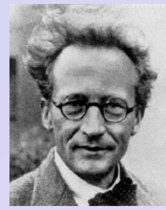
The larger the mass, the smaller the wavelength,
For very large masses, the wave character becomes negligible

Werner Heisenberg (1927)

Uncertainty Principle

Because of the dual nature of the electron, both the location and momentum of it cannot be known with absolute certainty

- The "Bohr orbit" idea violates this principle!



Erwin Schrödinger (1926)

Developed wave theory of the atom

- the foundation of quantum mechanics

Highly mathematical equations

Describe properties of e^- in atoms

And the probability of finding an electron in a given volume of space

The Schrödinger Equation

$$\hat{H}\Psi = E\Psi$$

- Nuclear kinetic energy
- Electron kinetic energy
- Nuclear/electron attraction
- Nuclear/nuclear repulsion
- Electron/electron repulsion

$$\hat{H} = -\sum_{A}^{nuc}\frac{\hbar^2}{M_A}\nabla_A^2 - \sum_{i}^{elec}\frac{\hbar^2}{m_e}\nabla_i^2 - \frac{1}{4\pi\epsilon_0}\sum_{i}^{elec}\sum_{A}^{nuc}\frac{Z_A e}{r_{iA}} + \frac{1}{4\pi\epsilon_0}\sum_{A}^{nuc}\sum_{B>A}^{nuc}\frac{Z_A Z_B}{R_{AB}} + \frac{1}{4\pi\epsilon_0}\sum_{i}^{elec}\sum_{j>i}^{elec}\frac{e^2}{r_{ij}}$$

So....definite planetary orbits of Bohr are replaced by *orbitals*

→ wave function

→ describe the region around the nucleus where electrons are most likely found

Electron Cloud - Visual image describing areas of probability of electron position

Electrons
→ What are they?
→ Where are they?
→ Why are they important?

Electronic Structure
→ number
→ distribution
→ energies

Quantum Theory

Designed to **explain** the electronic structure of atoms

Quantum Mechanical Model

- Treats electrons as both **waves** and **particles** (wave-particle duality)
- Location of electrons are described in terms of average regions of most **probable location** (called orbitals)
- "Electron cloud"
- Of most importance is the **energy** associated with the electrons (not position)
- Allowed energy states can be described by **quantum numbers**