Early Quantum Mechanics Review

1900 - Planck Explains Blackbody Radiation
1905 - Einstein Explains the Photoelectric Effect
   - Introduces the photon
   1914-16 - Experimental Confirmation by Millikin
   Accurate value of h, e - but photon not yet accepted
   Photon - "bold ... reckless"
1908 - Bragg-Barkla Controversy over X-Rays
   Bragg - X-rays are particles
1913 - The Bohr Model for Hydrogen (worked in Rutherford lab)
   - Predicted spectral lines
   - Model for stable atom
Bohr model - mix of classical and quantum

Problems with Model

Fine-structure - 1892 Michelson - Balmer lines are multiple lines
Sommerfeld - 3D model => 3 quantum numbers
   - used precessing ellipses + relativity
1897 - Zeeman Effect - splitting due to magnetism
1913 - Stark Effect - splitting due to electric fields

More Problems

Helium Spectrum - did not work - only 2 electrons!

Anomalous Zeeman Effect - multiplet structure of energy levels

Periodic Table - not understood, though Bohr predicted Z=72

Stern-Gerlach (1921)
   sent beam of atoms through inhomogeneous magnetic field
   should diffract into 2l+1 even piles for q-number l
   Ag - only 2 piles
Electron Spin

Solutions:

a) Sommerfeld and Lande
   - add new q-number for "core" electrons

b) 1924 Pauli - corrected (24 years old)
   - q-number only for valence electrons
   - only takes two values
   - each electron has a different set of (4) quantum numbers
     "Pauli Exclusion Principle"

1925 - Goudsmit and Uhelnbeck called it intrinsic spin

c) 1928 - Dirac "explained" with relativistic theory

The Compton Effect

1923 - Arthur Compton - scattering of X-rays from metal foil

X- Ray, $E = hf$, $p = h/\lambda$

Before

After

This in part lead to stopping Bohr's (and many others)
opposition to the photon in the early 20's.

Note: "Photon" - coined in 1926 by Chemist Gilbert Lewis

The Wavelength of Particles

1924 - Louis deBroglie explained Bohr's model by assuming that particles have wavelengths

Then only standing waves fit into a particular orbit.

Photons have energy $E = hf$ and momentum $mv = h/\lambda$.
Now, particles have wavelength $\lambda = h/mv$!

1927 - Davisson-Germer - diffraction of electrons
What is a Wave?

Waves - a disturbance that propagates, carrying energy

Types - transverse vs longitudinal

Properties of Waves
- wavelength, frequency, wavespeed, amplitude

Behavior of Waves
- reflection, refraction, dispersion
- interference, diffraction

Superposition of Waves

What happens when two waves try to occupy the same point in space at the same time?

http://www.kettering.edu/~drussell/Demos/superposition/superposition.html

Diffraction of Waves

Diffraction - the bending of waves around obstacles

Young's Double Slit Experiment
The Single Slit


\[ d \sin \theta = m \lambda \]
The deBroglie Wavelength - $\lambda = \frac{h}{mv}$

The wavelength of an electron: $m = 9.11 \times 10^{-31}$ kg, $v = 6.00 \times 10^6$ m/s

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34} \text{Js}}{(9.11 \times 10^{-31} \text{kg})(6.00 \times 10^6 \text{m/s})} = 1.2 \times 10^{-10} \text{m}$$

The wavelength of a baseball: 150 g ball moving at 13.0 m/s

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34} \text{Js}}{(0.15 \text{ kg})(13.0 \text{ m/s})} = 3.3 \times 10^{-34} \text{m}$$
Werner Heisenberg

Electrons moving in orbits - too classical!
Heisenberg - 23 years old
- should study observables
  - light hits atom, analyze emitted light
1925 (June) hayfever - went to an island and produced matrix mechanics
  \[ E = (n + 1/2) \hbar \]
  \[ \text{ab not equal to ba} \]
  Used complex numbers
1925 (Sept) Born-Jordan - formal exposition
  \[ xp - px = i \hbar \]
Dirac - developed theory at same time (younger!)
1925 (Nov) Born-Jordan-Heisenberg paper
Pauli - solved hydrogen atom

Problems: No physical picture! -- Bohr approved, Einstein did not

Erwin Schrödinger

Schrödinger - 38 years old

matrix methods are difficult
no visualization
  (Fermi almost gave up physics!)

1926 - New Theory - more comfortable
deBroglie waves \(\Rightarrow\) wave equation
Required a potential \(V\)
  \(V = 0\) \(\Rightarrow\) free particles
  otherwise \(\Rightarrow\) SHO, other models
1st attempt - relativistic - failed (no spin)
2nd attempt - nonrelativistic equation

The Wave Function

Schrödinger's wave equation produced the same results
as Heisenberg's matrix mechanics

The wave function and energies are determined

The wave function gives information about the state of the
electron - possibly representing a sum over several states
with corresponding energies

Useful for computing observables.

It produced an interpretation - though varying views arose.
Heisenberg’s Uncertainty Principle

\[ \Delta p \Delta y \geq \frac{\hbar}{4\pi} \]

"The more precisely the POSITION is determined, the less precisely the MOMENTUM is known"
Example

\[ \Delta p \Delta v \geq \frac{\hbar}{4\pi} \]

Position of an object is known to an uncertainty:

\[ \Delta y = 1.5 \times 10^{-11} \text{m} \]

The minimum uncertainty in momentum:

\[ \Delta p_y = \frac{\hbar}{4\pi \Delta v} = 3.5 \times 10^{-21} \text{kg m/s} \]

The minimum uncertainty in electron speed:

\[ \Delta v_y = \frac{\Delta p_y}{m} = 3.8 \times 10^6 \text{m/s} \]

The minimum uncertainty in the speed of a ping pong ball:

\[ \Delta v_y = \frac{\Delta p_y}{2.2 g} = 1.6 \times 10^{-2} \text{m/s} \]

Schrodinger's Cat: Half Dead - Half Alive?

Epic Poem on the Cat
Engines of Our Ingenuity