Waves or Particles?

Thursday, October 16, 2008
1:27 PM

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

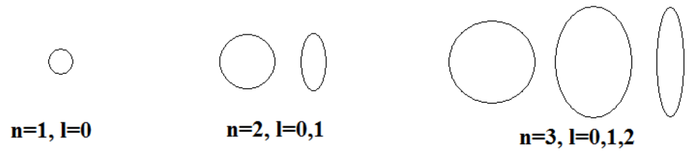
1913 - The Bohr Model for Hydrogen (worked in Rutherford lab)
- Predicted spectral lines
- Model for stable atom

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

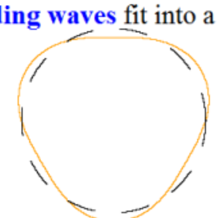
This in part lead to stopping Bohr's (and many others) opposition to the photon in the early 20's.

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

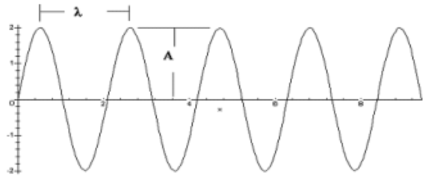
What is a Wave?

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

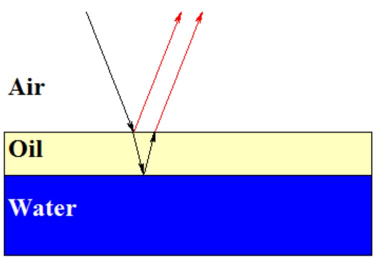


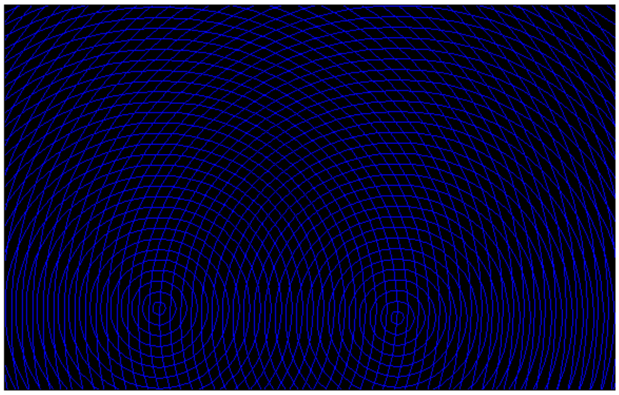
Superposition of Waves

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

Superposition of Waves
Wave Interference





Diffraction of Waves

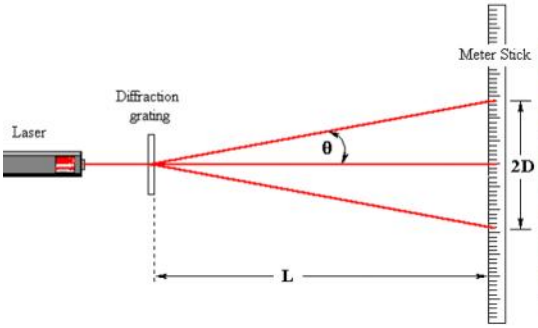
Diffraction - the bending of waves around obstacles

http://www.launc.tased.edu.au/online/sciences/physics/diffrac.html

Young's Double Slit Experiment
The Single Slit

http://surendranath.tripod.com/Applets/Optics/Slits/DoubleSlit/DblSltApplet.html

$$d \sin\theta = m\lambda$$



The deBroglie Wavelength - $\lambda = h/mv$

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

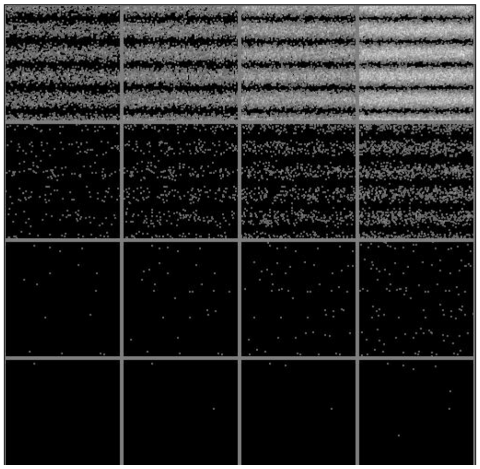
$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}\ \text{Js}}{(9.11 \times 10^{-31}\ \text{kg})(6.00 \times 10^{6}\ \text{m/s})} = 1.2 \times 10^{-10}\ \text{m}$$

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

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

http://www.lactamme.polytechnique.fr/Mosaic/images/DIFF.32.0.16.D/image.mpg

Electron Diffraction



Wave Mechanics

1924 - deBroglie's Thesis - Particles behave like Waves
1927 - Davisson-Germer Verified deBroglie's idea

Lead to a more complete "wave" theory of the electron

1925 - Matrix Mechanics - Heisenberg
1926 - Wave Mechanics - Schrodinger
1927 - Heisenberg's Uncertainty Prinicple

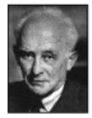
1928 - Relativistic Quantum Mechanics - Dirac

Later - QED and QCD

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)hf
    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

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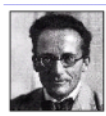


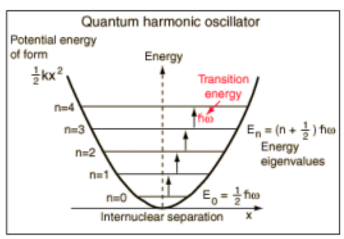
Erwin Schrodinger

Schrodinger - 38 years old

$$H\Psi = i\hbar\frac{\partial\Psi}{\partial t} \qquad \frac{-\hbar^2}{2m}\frac{\partial^2\Psi(x)}{\partial x^2} + U(x)\Psi(x) = E\Psi(x)$$

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

1926 - New Theory - more comfortable



deBroglie waves => wave equation
Required a potential V
    V=0 => free particles
    otherwise => SHO, other models
1st attempt - relativisitic - failed (no spin)
2nd attempt - nonrelativistic equation

The Wave Function

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

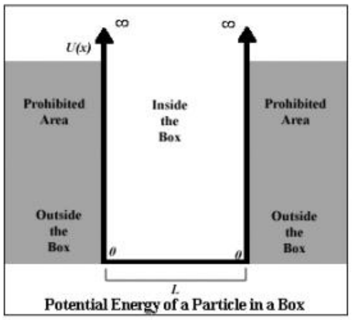
The wave function and energies are determined

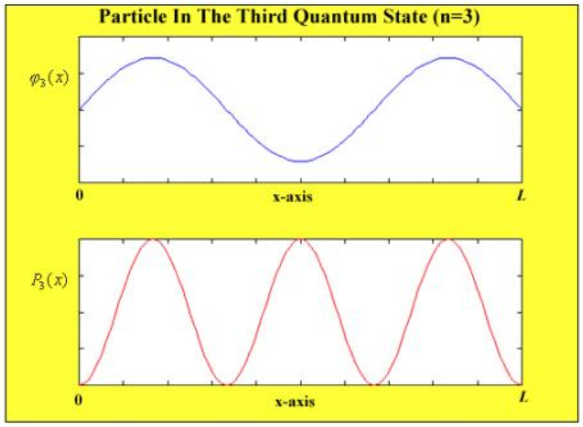
The wave function gives information about the state of the electron - possibly representing a sum over several states with corresponding energies

Useful for computing observables.

It produced an interpretation - though varying views arose.

Probability





Heisenberg's Uncertainty Principle

$$\Delta p_y \Delta y \geq \frac{h}{4\pi}$$

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

180 W. Heisenberg,

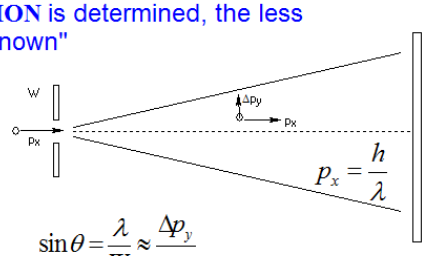
ermöglichen, als es der Gleichung (1) entspricht. so wäre die Quantenmechanik unmöglich. Diese Ungenauigkeit, die durch Gleichung (1) festgelegt ist, schafft also erst Raum für die Gültigkeit der Beziehungen, die in den quantenmechanischen Vertauschungsrelationen

$$pq - qp = \frac{h}{2\pi i}$$

ihren prägnanten Ausdruck finden; sie ermöglicht diese Gleichung, ohne daß der physikalische Sinn der Größen p und q geändert werden müßte.

Für diejenigen physikalischen Phänomene, deren quantentheoretische Formulierung noch unbekannt ist (z. B. die Elektrodynamik), bedeutet Gleichung (1) eine Forderung, die zum Auffinden der neuen Gesetze nützlich sein mag. Für die Quantenmechanik läßt sich Gleichung (1) durch eine geringfügige Verallgemeinerung aus der Dirac-Jordanschen Formulierung herleiten. Wenn wir für den bestimmten Wert η irgend eines Parameters den Ort q des Elektrons zu q' bestimmen mit einer Genauigkeit q_1, so können wir dieses Faktum durch eine Wahrscheinlichkeitsamplitude $S(\eta, q)$ zum Ausdruck bringen, die nur in einem Gebiet der ungefähren Größe q_1 um q' von Null merklich verschieden ist. Insbesondere kann man z. B. setzen

$$S(\eta, q) \text{ prop } e^{-\frac{(q-q')^2}{2q_1^2} - \frac{2\pi i}{h} p'(q-q')}, \text{ also } S\bar{S} \text{ prop } e^{-\frac{(q-q')^2}{q_1^2}}. \qquad (3)$$



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

$$\sin\theta = \frac{\lambda}{W} \approx \frac{\Delta p_y}{p_x}$$

$$\Delta p_y \approx \frac{h}{W} = \frac{h}{\Delta y}$$

$$\Delta p_y \Delta y \approx h$$

Example

$$\Delta p_y \Delta y \geq \frac{h}{4\pi}$$

Position of an object is known to an uncertainty:

$$\Delta y = 1.5 \times 10^{-11}\,\text{m}$$

The minimum uncertainty in momentum:

$$\Delta p_y = \frac{h}{4\pi \Delta y} = 3.5 \times 10^{-24}\,\text{kg m/s}$$

The mininmum uncertainty in electron speed:

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

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

$$\Delta v_y = \frac{\Delta p_y}{2.2g} = 1.6 \times 10^{-21}\,\text{m/s}$$

Schrodinger's Cat: Half Dead - Half Alive?

Epic Poem on the Cat

Engines of Our Ingenuity

http://www.straightdope.com/columns/read/113/the-story-of-schroedingers-cat-an-epic-poem