Quantum Waves

de Broglie’s “matter wave” hypothesis implies energy levels in atoms must be quantized as Bohr had hypothesized *ad hoc*.

The wave nature of electrons, protons, atoms and even molecules has been observed using double slit experiments (analogous to Young’s 1801 expt. that showed light is a wave.)

But what’s waving?

An electron in a double slit expt. has a probability of landing on each part of the screen given by its wave function, $\psi$ (psi)
Probability Waves

Much of quantum physics involves using the wave function to predict observable outcomes.

In addition to *interference* (e.g. double slit expt.) another wave phenomenon is *diffraction*: the spread of a wave after passing through an opening.
Diffraction

After the opening, the waves are traveling in all directions.
Single Slit Diffraction

Light passing through a narrow slit (width: \( W \)) will produce a pattern of fringes on the screen.

Called a *single-slit diffraction pattern*.

The **Central Fringe’s** angular size depends on wavelength and \( W \): 

\[
2\theta_r = \frac{2\lambda}{W}
\]
So, if we make the slit narrower (decrease $W$) then the fringe... gets bigger.
Diffraction fringes can also be observed by holding your finger and thumb very close together. Or two pens....
Diffraction Experiment: Poisson’s Bright Spot:
Shine a laser through a reflecting telescope.

Images from http://www.princeton.edu/~rvdb/
Poisson’s Bright Spot

Images from http://www.princeton.edu/~rvdb/
Fire electrons in the x direction at a single slit.
They spread out somewhat in the y direction

Width, $\theta$, given by:

$$\sin \theta = \frac{\lambda}{W}$$
Constraining *Position Affects Momentum*

If we make the slit *smaller*, electrons spread out *more*.

Notes:

1.) Making a slit smaller means reducing the uncertainty in *y-position*: $\Delta y$

2.) If the beam is more spread out, we say that the beam has a larger uncertainty in its *y-momentum*: $\Delta p_y$
Heisenberg Uncertainty Principle

The better we know a particle’s location (position) the worse we know its momentum.

Mathematically, this can be expressed as the Heisenberg Uncertainty Principle

\[ \Delta x \Delta p \approx \hbar. \]

\( h = \text{Planck’s constant.} \)

Since \( h \) is so small, it’s almost impossible to observe effects of the Uncertainty Principle in everyday life.
Heisenberg Uncertainty Principle

An object does not fundamentally have a momentum and a position simultaneously.

This is **not** due to an inability to make precise measurements.

Is an example of what Bohr called “Complementarity”

H.U.P. has many practical consequences...like Quantum Tunneling....in microscopes or the Sun.
Tip of microscope

Electrons tunnel across this gap.

Atomic surface

STMs can image individual atoms