Major Steps in the Development of Quantum Theory

1900 Max Planck postulated that energy is quantized. This solved the problem (called the ultraviolet catastrophe) classical physics had with black body radiation. For this Planck received a Nobel Prize in 1918.

Planck's constant: $\mathbf{h} = 6.626 \times 10^{-34}$ J·s

1905 Albert Einstein postulated that electromagnetic radiation is quantized as photons. This provided an explanation for the photoelectric effect. For this Einstein received a Nobel Prize in 1921.

1 photon has energy $\mathbf{E = h\nu}$, where ν is the frequency of the electromagnetic radiation.

1913 Niels Bohr postulated that electrons in the hydrogen atom move in discreet (quantized) **orbits** with quantum numbers n = 1, 2, 3, … His Nobel Prize was in 1922.

The orbits have radii: $r_n = a_0 n^2$ and energy levels: $E_n = -k/n^2$, where $k = 2.179 \times 10^{-18}$ J.

1924 Louis de Broglie postulated that all moving particle coexist as waves with a wavelength:

$\boldsymbol{\lambda = h/p}$ where p = momentum = m·u = mass ×speed

It is this wave property of electrons that provides the basis of the electron microscope. His Nobel Prize was in 1929.

1925-7 Werner Heisenberg developed quantum theory in which he postulated his Uncertainty Principle (1927): that because of the wave nature of matter, complimentary physical properties cannot be known with precision at the same time.

Mathematically, $\mathbf{\Delta x \cdot \Delta p \geq h/4\pi}$ where Δx is uncertainty in position, Δp is uncertainty in momentum (Δp = m·Δu) One or the other can be known precisely, but not both simultaneously. Notice that kinetic energy = $\frac{1}{2} mu^2 = p^2/(2m)$. So position and energy cannot be known simultaneously within limits.

Heisenberg was awarded (in 1932) a Nobel Prize "for the creation of quantum mechanics". Before Heisenberg (and Schrödinger) was the "old" quantum theory; after Heisenberg, the "new" quantum theory.

1926 Erwin Schrödinger set forth his famous (time-independent) equation $\mathbf{\hat{H}\psi = E\psi}$. $\hat{H}$ is the Hamiltonian operator with kinetic energy plus potential energy in which classical momentum, p , has been replaced by a differential operator (e.g., $-i\hbar\frac{\partial}{\partial x}$ for p_x , momentum in the x direction).

ψ (Greek letter psi) is the wavefunction, which has a value at every point (x, y, z) in space and thus contains the information for a particle. E is the energy. The **probability density** for finding a particle anywhere in space is given by $|\psi|^2$. The region in space containing 90% of the probability density is called an **orbital**. Schrödinger (along with Dirac, who derived quantum theory consistent with relativity) received a Nobel Prize in 1933.