Rudiments of Quantum Mechanics (QM)

- Principle of complementarity: all entities have both particle and wave properties
  - Particle properties include mass, charge, energy, momentum, and angular momentum
  - Wave properties typically involve interference phenomena
  - No experiment can measure both kinds of properties at the same time (they "complement" each other)
- Uncertainty principle: certain pairs of particle properties cannot be simultaneously measured with complete accuracy
  - These pairs include position in some direction *and* momentum in the same direction, as well as energy *and* amount of time spent with that energy
  - The best one can do is $\Delta p \Delta x = \hbar / 2$, for position and momentum, or $\Delta E \Delta t = \hbar / 2$, for energy and time; the Δs indicate "uncertainty in" and $\hbar$ = 1.06×10^{-34} J-s ($\hbar$ is pronounced "h-bar")
  - Because $\hbar$ is small compared with macroscopic quantities, QM effects show up most dramatically for small entities such as electrons, nuclei, atoms, and molecules
- Wavefunction: the dynamical state of an entity is described by a smoothly continuous function of position and time that satisfies a partial differential equation called the Schrödinger Equation (SE)
  - The SE takes a slightly different form depending on what forces the entity experiences
  - The wavefunction contains all information that in principle can be obtained about an entity
  - Dynamical information is extracted from the wavefunction by acting on it with mathematical operators
    - In particular, differentiating the wavefunction with respect to time corresponds to measuring the entity's energy; differentiating with respect to position corresponds to measuring the entity's momentum
  - In some cases, the forces acting on an entity will confine it to some finite region of space (such as the electric interaction between an electron and a proton in a hydrogen atom)
    - In that event, the wavefunction can take on a discrete set of "standing wave" shapes, each of which has its own set of measured quantity values; the permitted values are said to be "quantized" (which is the origin of the "quantum" in QM)
    - The permitted standing wave solutions of the SE explain why atoms are stable (there's a lowest energy electron standing wave—the "ground state") and why they radiate only certain colors (transitions between permitted standing wave states involve only certain energies and for a photon energy = color)
  - The "wavy" part of the wavefunction deals with probability
    - In any one measurement of a given quantity only one of the permitted values will show up, but we never know for sure which

        - There is now excellent experimental evidence that this condition of unpredictability is not because QM is incomplete, but rather because nature is inherently random in the microrealm
        - The wavefunction is a complex-valued function and its *modulus squared* (the product of the function with its complex conjugate) is interpreted as the probability per unit volume of finding the entity at some point in space at some time with the permitted quantity values
        - The squared modulus is also used to calculate the average values of measured quantities when the measurement is performed again-and-again
- <u>Spin</u>: a quantum entity carries intrinsic angular momentum called "spin"
    - Spin comes in units of $\hbar$
    - There are two types of spin: (odd integer)$\hbar/2$ and (integer)$\hbar$; entities of the first type are called "fermions" while those of the second type are called "bosons"
    - Examples of fermions are electrons, protons, and neutrons (all with spin = $\hbar/2$, "spin ½"), and any system consisting of an odd number of fermions (such as a ^{3}He atom [2 electrons, 2 protons, 1 neutron]); examples of bosons are photons (spin = $\hbar$, "spin 1"), any system consisting of only bosons, and any system consisting of an even number of fermions (such as a ^{4}He atom [2 electrons, 2 protons, 2 neutron])
    - Fermions tend to "dislike" one another; no two identical fermions (e.g., two electrons) whose wavefunctions overlap can be in the same state of motion; this dislike is known as the <u>Pauli Exclusion Principle</u> and is the reason why atoms with different numbers of electrons have different chemical behaviors
    - Bosons, on the other hand, "like" each other; identical bosons (e.g., photons) prefer to be in the same state (if they can); this tendency gives rise to superfluidity (fluids with no viscosity) and superconductivity (electronic elements with no resistance)