Lecture : March 23, 2020

Quantum Spin

REVIEW:

- (1) quantum particles act sometimes like waves and some times like particles:

  Experiments that confirm this wave-particle duality are:

  (A) For photons, it was photoelectric effect and Compton effect that showed that electromagnetic waves have particle properties.

  (B) For electrons (and other quantum particles) , it is double slit experiment and scattering of electrons from a crystal...There is interference pattern, something that is produced by waves and not particlesḂohr orbits are also consistent with wave picture of electrons.

- (2) Wave- Particle duality of particles with mass are described by Schödinger equation which give wave function ψ. Note once you solve Schödinger equation, ψ is know at all times and at all locations. $|\psi|^2$ – looks like a wave – , gives probability of finding the particle and is a probability wave.

- (3) Weird quantum properties are Heisenberg uncertainty principle: says that position and momentum cannot be simultaneously determined.
  , tunneling that explained radioactivity - where particles without enough energy can end up on the other side of the hill.
  and Zero point energy- like particle confined in a box cannot be at rest.

- (4) It was found that electron "acts" like a spinning top, Spin is denoted as S is a kind of intrinsic angular momentum - that is, it NEVER stops spinning. It is equal to $\pm\hbar/2$. That is spin can take only be either $+\frac{\hbar}{2}$ or $-\frac{\hbar}{2}$, usually called spin-up and spin-down.

  Pauli introduced some modification of the Schödiner equation to include spin: When $S = +\frac{\hbar}{2}$ it is described by a wave function ψ_1 and when $S = -\frac{\hbar}{2}$, it is described by wave function ψ_2.

This means that given an electron, it can exist in two states, described by ψ_1 and ψ_2.

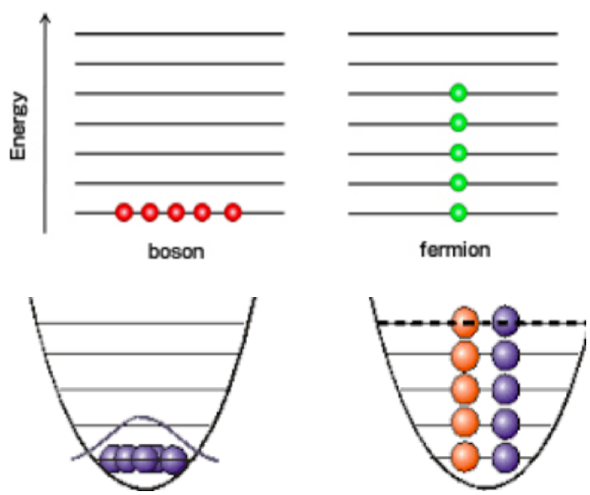
- (5) As a consequence of spin, electron acts like a little "magnet". The strength of its magnetic property, called magnetic moment is $\mu = g\frac{q}{m}S$. Here q is the charge of the electron and m is the mass of the electron.

- (6) Fermions and Bosons:

  All particles of nature have spin that is either:

  (a) Half-integer multiples of $\hbar$, that is, $\frac{1}{2}\hbar$, $\frac{3}{2}\hbar$, $\frac{5}{2}\hbar$... Such particles are called Fermions.

  (b) or Integers, like $0, \hbar, 2\hbar, 3\hbar....$, such particles are called Bosons.



  Examples are photons (spin 1), π-mesons (spin zero), gravitons (spin -2).

  (c) There are NO particles in nature that have spin $\frac{1}{3}\hbar$, $\frac{1}{8}\hbar$ etc...

BOSONS and FERMIONS

<https://www.youtube.com/watch?v=_1S6KfMzOH8>

Pauli Exclusion Principle and Atoms with more than one electron

Each quantum state (specified by the quantum number such as n) of an atom can accommodate only two electrons. Known as the Pauli exclusion principle, it explains the buildup

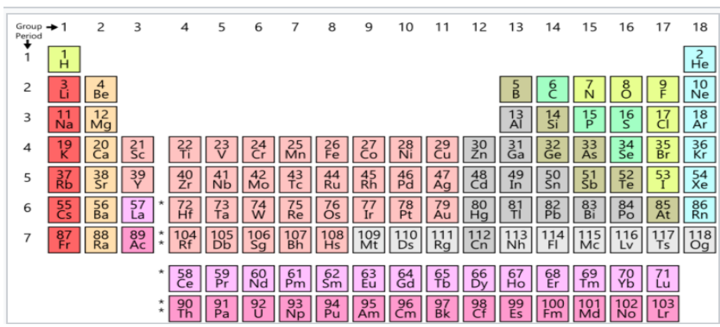


FIG. 1: The Periodic Table is a tabular display of all the known elements, which are arranged by atomic number, electron configuration, and recurring chemical properties. The structure of the table shows periodic trends. The seven rows of the table, called periods, generally have metals on the left and nonmetals on the right.

of elements, the Periodic Table.

Difference between classical and Quantum Particles

- Indistinguishability

- Only two kinds of particles: fermions and bosons
- Exclusion principle
- Key difference between integer and half integer spin particles: After 2π rotations, wave functions do not return to their starting value. We need 4π rotations to recover initial state.

What is $\hbar$???

- $\hbar$ determines the minimum uncertainty in classical observables...
- Spin of all elementary particles is either an integral or half integral multiple of $\hbar$.

I. IMPORTANT REMARKS

- **Pauli Exclusion Principle... Pauli's New Force**

  Pauli's exclusion principle that two electrons cannot be in the state state ultimately prohibits two electrons too close together. The "effective force" generated by Pauli exclusion principle is called the "exchange force".Note it is not a new kind of force – it is not really a force – (there are only four types of fundamental forces in nature: gravitational, electromagnetic, Nuclear Force and Weak Force). It is an EFFECTIVE force that is, it can be viewed as a kind of force.

- NOTE: Pauli exclusion principle applies only to *Identical Fermions*–
- When we swap two electrons, there is NO way to detect the swap – experimentally or even in principle.
- Pauli exclusion principle explains why we cannot walk through a solid wall, even though it is 99 percent empty. The electrons of our hand cannot penetrate the "wall" atoms because they are ruled by Pauli exclusion principle.
- We understand why matter is made up of only fermions. If bosons were the building blocks of matter, it will be unstable.

- Yes, quantum physics is the key to understand all physical phenomena (almost all...), only in principle. The devil is in the details.... Even though we know all the forces, we cannot always solve Schrödinger equation....

Spin and Stability of the World

Pauli exclusion principle is the reason why electrons do not cluster into the lowest orbits. Therefore, it is the key to the stability of an atom and hence the universe.