Basics of Quantum Mechanics

Subject: Quantum Physics I
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Class Objectives

This class aims to help students understand:

- The necessity of quantum mechanics beyond classical physics.
- The fundamental differences between classical and quantum perspectives.
- The role of probability and uncertainty in quantum systems.
- The concept of wave-particle duality and its experimental verification.
- How quantum mechanics explains microscopic phenomena like photon-atom interactions and electron flow in semiconductors.

Why Quantum Physics?

- Classical mechanics (Newton's mechanics) and Maxwell's equations (electromagnetics theory) can explain MACROSCOPIC phenomena such as motion of billiard balls or rockets.
- Quantum mechanics is used to explain microscopic phenomena such as photon-atom scattering and flow of the electrons in a semiconductor.
- QUANTUM MECHANICS is a collection of postulates based on a huge number of experimental observations.
- The differences between the classical and quantum mechanics can be understood by examining both
  - The classical point of view
  - The quantum point of view

Classical Point of View

- In Newtonian mechanics, the laws are written in terms of PARTICLE TRAJECTORIES.
- A PARTICLE is an indivisible mass point object that has a variety of properties that can be measured, which we call observables. The observables specify the state of the particle (position and momentum).
- A SYSTEM is a collection of particles, which interact among themselves via internal forces, and can also interact with the outside world via external forces. The STATE OF A SYSTEM is a collection of the states of the particles that comprise the system.
- All properties of a particle can be known to infinite precision.

Conclusions:

TRAJECTORY ➔ state descriptor of Newtonian physics,

EVOLUTION OF THE STATE ➔ Use Newton's second law

PRINCIPLE OF CAUSALITY ➔ Two identical systems with the same initial conditions, subject to the same measurement will yield the same result.

Quantum Point of View

- Quantum particles can act as both particles and waves ➔ WAVE-PARTICLE DUALITY
- Quantum state is a conglomeration of several possible outcomes of measurement of physical properties ➔ Quantum mechanics uses the language of PROBABILITY theory (random chance)
- An observer cannot observe a microscopic system without altering some of its properties. Neither one can predict how the state of the system will change.
- QUANTIZATION of energy is yet another property of "microscopic" particles.

Heisenberg Uncertainty Principle

•One cannot unambiguously specify the values of particle's position and its momentum for a microscopic particle, i.e.

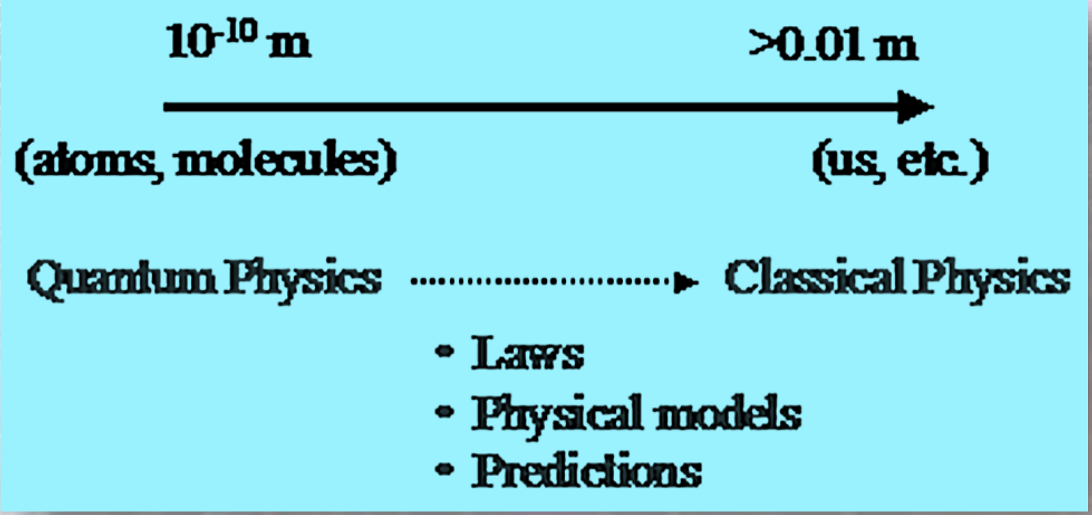
$$\Delta x(t_0) \cdot \Delta p_x(t_0) \geq \frac{1}{2}\frac{h}{2\pi}$$

•Position and momentum are, therefore, considered as incompatible variables.

•The Heisenberg uncertainty principle strikes at the very heart of the classical physics => the particle trajectory.

The Correspondence Principle

When Quantum physics is applied to macroscopic systems, it must reduce to the classical physics. Therefore, the nonclassical phenomena, such as uncertainty and duality, must become undetectable. Niels Bohr codified this requirement into his Correspondence principle:



Particle-Wave Duality

- The behavior of a "microscopic" particle is very different from that of a classical particle:
  - in some experiments it resembles the behavior of a classical wave (not localized in space)
  - in other experiments it behaves as a classical particle (localized in space)
- Corpuscular theories of light treat light as though it were composed of particles, but can not explain DIFRACTION and INTERFERENCE.
- Maxwell's theory of electromagnetic radiation can explain these two phenomena, which was the reason why the corpuscular theory of light was abandoned.

Particle-Wave Duality

Waves as particles

- Max Plank work on black-body radiation, in which he assumed that the molecules of the cavity walls, described using a simple oscillator model, can only exchange energy in quantized units.
- 1905 Einstein proposed that the energy in an electromagnetic field is not spread out over a spherical wavefront, but instead is localized in individual clumbs - quanta. Each quantum of frequency n travels through space with speed of light, carrying a discrete amount of energy and momentum =photon => used to explain the photoelectric effect, later to be confirmed by the *x*-ray experiments of Compton.

Particles as waves

- Double-slit experiment, in which instead of using a light source, one uses the electron gun. The electrons are diffracted by the slit and then interfere in the region between the diaphragm and the detector.
- Aharonov-Bohm effect

Summary

•**Need for Quantum Mechanics:** Classical physics fails at microscopic scales; quantum mechanics explains atomic and subatomic phenomena.
•**Key Differences:** Classical mechanics is deterministic (particle trajectories), while quantum mechanics is probabilistic (wave functions).
•**Core Principles:**
•**Wave-Particle Duality:** Particles exhibit both wave-like and particle-like behavior.
•**Heisenberg Uncertainty Principle:** Position and momentum cannot be precisely determined simultaneously.
•**Energy Quantization:** Energy is exchanged in discrete units (quanta).
•**Correspondence Principle:** Quantum mechanics aligns with classical physics at large scales.
•**Experimental Evidence:**
•**Planck's Black-Body Radiation** and **Einstein's Photoelectric Effect** confirm energy quantization.
•**Double-Slit Experiment** demonstrates particle-wave duality.
•**Aharonov-Bohm Effect** shows quantum influence of electromagnetic potentials..

Useful Links

Particle-Wave Duality explanation

http://www.youtube.com/watch?v=DfPeprQ7oGc