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Quantum Formalism

Overview

1. Introduction
2. Copenhagen Interpretation
3. Double-slit

Introduction

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Quantum Tea

- Quantum tea is a series of lectures (“roundtable-stile”) organized by the Zaiku group
- The initial idea is to have discussions concerning the different Quantum Mechanics interpretations
- After this initial part, we plan to discuss a list of important papers related to this topic in detail.

Examples

- Einstein, Podolski, Rosen, questioning the completeness of Quantum Mechanics
- Bell, and his famous inequalities
- Schrödinger, with his famous cat-paradox treating the problem of quantum interference for macroscopic objects
- Bohm, who proposed a non-local theory of hidden variables for quantum mechanics following de Broglie's ideas
- Everett, who introduced the many-world interpretation
- and many others (...)

Copenhagen Interpretation

- The expression “Copenhagen Interpretation” refers to the large influence of Niels Bohr in the comprehension of QM
- This interpretation gathers a common view related to indeterminism, discreteness and indivisibility of nature, absence of causality, and the idea that the goal of science is not to understand nature how it is but just to understand what we can get when doing experiments
- However the main idea is that the goal of science is not to understand nature how it is, but just to understand what we can get when doing experiments. In Niels Bohr’s words:

“There is no quantum world. There is only an abstract physical description. It is wrong to think that the task of physics is to find how nature is. Physics concerns what we can say about nature.”

- Bohr, Heisenberg, Born, Pauli, and many others are adept from the philosophical current of thinkers named positivism whose main founders are people such as E. Kant, D. Hume, E. Mach, etc
- In summary, for this group of thinkers, the only way to get knowledge is by the scientific method, and in a more radical formulation called idealism, even the scientific method is superfluous
- Since all observation is given by our senses, science is just a logical consequence of human experience
- Thus, the idea of an existence of reality independent of human perception can never be tested for us, since it will always have intermediation of our senses

Given these philosophical premises, the idea behind the Copenhagen interpretation defenders about quantum phenomena can be summarized in this way

1. The quantum phenomena are random, unpredictable, and unique
2. It is not possible to give any properties to a quantum particle before these properties are observed
3. Certain quantum particle properties can not coexist: when one tries to introduce a new property, old properties introduced previously can be destroyed

- The conclusion is that it is not possible to attribute states of reality for quantum particles independent of human observation
- So, how to describe the quantum processes and connect them with the reality of facts?

The answer was given by the hard work of brilliant scientists. The result of these ideas can be summarized in the basic postulates proposed by J. von Neumann (this list is not consensual, even among the Copenhagen interpretation supporters and much less among other interpretation defensors)

The Postulates of Quantum Mechanics

- $\Psi)$ Any state of a quantum system at time t_0 is characterized by a vector (ket) $|\psi(t_0)\rangle$ that belongs to the Hilbert space. This vector in Hilbert space describes completely the physical state of the system. Everything that can be said about the system is contained in $|\psi(t_0)\rangle$
- $\Psi)$ Every measurable physical quantity is described by a self-adjoint operator (called observable) acting in the Hilbert space of the system
- $\Psi)$ The only possible result of a measurement of a physical quantity is one of the eigenvalues of the self-adjoint operator associated with it

The Postulates of Quantum Mechanics

- $\Psi)$ The probability of finding one of the eigenvalues (for example, a_n) associated with the observed quantity is given by (in the discrete case):

$$\mathcal{P}(a_n) = \sum_{i=1}^{g_n} |\langle u_n^i|\psi\rangle|^2 = \langle\psi|P_n|\psi\rangle$$

  where P_n is the projector over the eigensubspace of the Hilbert space with eigenvalue a_n. $|u_n^i\rangle$ is one of the eigenstates with this eigenvalue with degeneracy g_n.
- $\Psi)$ After a measurement generating the eigenvalue a_n, the state of the system collapses to

$$|\psi'\rangle = \frac{P_n|\psi\rangle}{\sqrt{\langle\psi|P_n|\psi\rangle}}$$

The Postulates of Quantum Mechanics

Ψ) The evolution of the state vector while no experiments are carried out is governed by the Schrödinger equation:

$$i\hbar \frac{d|\psi(t)\rangle}{dt} = H|\psi(t)\rangle$$

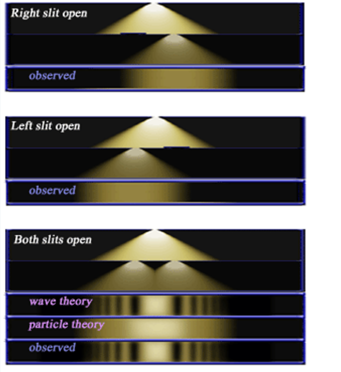
where $H(t)$ is the Hamiltonian operator of the system.
In the Heisenberg description, the observable A varies with time using the equation

$$\frac{dA}{dt} = \frac{i}{\hbar}[H, A]$$

while the quantum state remains constant.

Double-slit

Let us use these postulates to describe the double-slit experiment



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