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Quantum Formalism

Overview

1. **Many-Worlds Interpretation II**

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- Ψ) The main goal of Everetian theory is to get a formulation of QMs that can be applied to any physical system (including closed systems, like the Universe)
- Ψ) In other words, Everett would like to generalize QM, taking out any reference to the exterior classical world
- Ψ) The determinism of this formulation is described by ψ that obeys the Schrödinger equation and its value at any time is perfectly determined by the initial conditions
- Ψ) In this context, we have a total absence of probabilities and the collapse postulate is not valid
- Ψ) Everett says that if the state of a system is entangled, it is not possible to define univocally the state of the sub-system two (S_2) without referring to the state of the subsystem one (S_1)- The state S_2 is always relative to the state S_1

- Ψ) This relation is univocally determined by the following entangled state

$$|\psi\rangle = \sum_{ij} c_{ij}|s_i\rangle_1 \otimes |r_j\rangle_2 \tag{1}$$

where $|s_i\rangle_1$ and $|r_j\rangle_2$ are complete basis in Hilbert spaces H_1 and H_2 from system S_1 and S_2, respectivelly

- Ψ) Thus, the state of the system S_2 relative to the state $|s_j\rangle_1$ from S_1 can be defined by

$$|\psi\rangle_{2(rel1)} = N_i \sum_{j} c_{ij}|r_j\rangle_2 \tag{2}$$

where N_i is a normalization constant,

- Ψ) In the Copenhagen interpretation, Eq. (2) gives origin to the conditional probability from each measurement done in system S_2 given that the system S_1 was observed in state $|s_i\rangle_1$
- Ψ) The total state can be re-written as:

$$|\psi\rangle = \sum_i \frac{|s_i\rangle_1}{N_i} \otimes |\psi\rangle_{2(rel1)} \tag{3}$$

- Ψ) Thus, the state of a sub-system (S_2) is defined only in relative terms of any other state of the sub-system (S_1) that is part of the total system
- Ψ) The quantum description from a measurement gives us an entangled state

$$|\psi_F\rangle = \sum_i c_i |s_i\rangle \otimes |\phi_A(s_i)\rangle \tag{4}$$

where $|\phi_A(s_i)\rangle = \int f(x)|x + \lambda s_i\rangle dx = \int f(x - \lambda s_i)|x\rangle dx$ (see quantum tea # 6), x is the position of the center of mass of the pointer in the apparatus, and $|s_i\rangle$ are the eigenstates from the measured operator with eigenvalues s_i

- Thus, we can not define an absolute state to the pointer, its states can only be defined relatively to the eigenstates $|s_i\rangle$ of the measured operator
- In this case, $|\phi_A(s_i)\rangle$ is the state of the pointer relative to the eigenstate $|s_i\rangle$
- Now, imagine that we put a second apparatus to measure the operator $\hat{S}$ with eigenstates $|s_i\rangle$ and an operator $\hat{X}$ for the position of the pointer
- We will find the final wave function

$$|\psi_F\rangle = \sum_i c_i |s_i\rangle \otimes |\phi_A(s_i)\rangle_1 \otimes |\phi_A(s_i)\rangle_2 \tag{5}$$

where $|\phi_A(s_i)\rangle_{1(2)}$ represents apparatus 1(2), and

$$|\phi_A(s_i)\rangle_1 = \int f_1(x_1 - \lambda_1 s_i)|x_1\rangle dx_1, \tag{6}$$

$$|\phi_A(s_i)\rangle_2 = \int f_2(x_2 - \lambda_1 s_i, y_1 - \lambda_1\lambda_2 s_i)|x_2, y_1\rangle dx_2 dy_1 \tag{7}$$

here again, the state relative to $|s_i\rangle$ is $|\phi_A(s_i)\rangle_1 \otimes |\phi_A(s_i)\rangle_2$

- $\Psi)$ If we put another apparatus (as in a von Neumann chain) that would measure the two apparatus (A_1, A_2) and the state $|s_i\rangle$ we would get the same result:

  The relative states $|s_i\rangle$ are states of experimental apparatus, which may represent observers registering the same eigenvalue s_i

- $\Psi)$ The final state described by Eq. (5) is a superposition of several branches, each one with their respective relative states to the system measured and its measurement apparatus

Interpretations

Ψ) If the different branches of Eq. (5) describe the different possible realities from the measurement, they must contain different states of the observers since each one measures only one of the possible values and never the complete set of possibilities.

Thus, now the point is: What are these states? In the Everett view, they have reality

- Some possibilities would say that these states could be different minds, worlds, or universes.

Many-Minds, Many-Worlds, & Many-Universes

- Ψ) In the first case, the word "mind" can be understood as a sequence of data kept in the physical system of the observer, called "memory", see Lockwood [2]
- Ψ) This approach has several consequences in neuroscience and philosophy
- Ψ) In another approach, the different branches represent different physical systems
- Ψ) In this case, would exist a multiplicity of universes, as suggested by DeWitt [3], represented by a unique and universal wave function that branches every time a quantum measurement is done
- Ψ) These ramifications of universes are contested by some authors since it could violate energy conservation
- Ψ) However, since the different universes never interfere with each other, none of them knows about the existence of the others, and in the interior of each universe the conservation of energy is valid.

Many-Minds, Many-Worlds, & Many-Universes

- Ψ) The Many-Worlds approach is viewed as something in between the other two
- Ψ) Following Lev Vaidman [4], the notion of the world is something subjective in the observable mind. The only entity that is not subjective is the Universe since it contains all possible worlds
- Ψ) In this approach, the notion of the world is defined by the observer's mind: a chain of events that is perceived by him/her and it is denominated in this form
- Ψ) This approach is closer to the definition of "mind" described before, and the perception of the observer is stimulated by sensations originating by local physical interactions
- Ψ) In this way, a world that makes sense to an observer, can not be built by non-local states, there is no, non-local sensible world

Example: Measurement

- $\Psi)$ The necessity to have a localized world implies in a different form to select the pointer in Eq. (4) $\Rightarrow |\psi_F\rangle = \sum_i c_i |s_i\rangle \otimes |\phi_A(s_i)\rangle$, without the necessity of decoherence
- $\Psi)$ This equation could also be written in terms of the other basis: $|\phi_A(r_j)\rangle = \sum_i |\phi_A(s_i)\rangle\langle\phi_A(s_i)|\phi_A(r_j)\rangle$, in the form

$$|\psi_F\rangle = \sum_j d_j |r_j\rangle \otimes |\phi_A(r_j)\rangle \tag{8}$$

- $\Psi)$ However, $|\phi_A(r_j)\rangle$ is not a localized state, it is a superposition of localized states ($|\phi_A(s_i)\rangle$) and can not represent a world for the observer.
- $\Psi)$ Thus, the only possible expansion for localized worlds is Eq. (4), and the role of decoherence is just to justify the inexistence of observers with non-local perceptions

Example2: Quantum Interference

Let's understand the experiment of quantum interference in Everett's theory

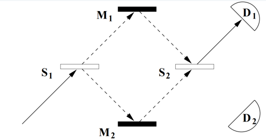

Figure: Mach-Zender Interferometer. Source: Ref. 4

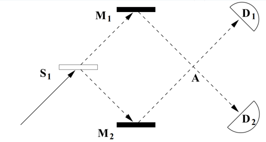

Figure: Mach-Zender Interferometer without second Beam-Splitter

Example2:Quantum Interference

- Ψ) In an experiment of quantum interference, the quantum particle is detected only by D_1 if we put two BS (top Fig.)
- Ψ) If we remove the second BS (down Fig.) or put an absorption screen before mirror $M_1(M_2)$ the particle can be detected by D_1 or D_2
- Ψ) David Deutsch says that the thing that interferes with the particle behaves like a particle without leaving a record of its existence, even on the screen
- Ψ) His logical conclusion is that the quantum particle is never detected by D_2 (top Fig.) due to the interference with another quantum particle that is in the "other world", that emerged in beam-splitter 1 (S_1)
- Ψ) After the bifurcation (S_1), both worlds are identical, apart from the particles that are following different trajectories
- Ψ) When they meet each other again in S_2 both worlds become identical the interference happens, thus one world can be noticed by the other

References

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