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Collapses Without Measurements

María Esther Burgos
Universidad de Los Andes, Facultad de Ciencias, Mérida, Venezuela
ORCIDiD:0000-0003-2954-2826

ABSTRACT

In quantum mechanics the state vector evolves in a predictable and continuous way, according to the Schrödinger equation; only if a measurement takes place, the Schrödinger evolution is interrupted. Transitions between stationary states (transitions BSS) are accounted for time dependent perturbation theory (TDPT). It is often ignored that this theory requires measurements. As measurements demand either the intervention of an observer or the interaction between the quantum system with a measuring device, billions of observers and/or measuring devices would be necessary at every small corner of the universe where transitions BSS take place. Nevertheless, there is no evidence of their existence. We are thus led to conclude that transitions BSS are the result of causes different from the measurements required in TDPT. In the spontaneous projection approach, the version of quantum mechanics which we uphold, collapses to the stationary states result from the tendency of the system to jump to the eigenstates of the constants of the motion.

Keywords: Transitions between Stationary States, Time Dependent Perturbation Theory, Quantum Measurements, Ambiguity and Incoherence of Orthodox Quantum Mechanics

INTRODUCTION

The first formalism of quantum mechanics was introduced by Paul Dirac in 1930 [1]. Two years later John von Neumann published Mathematische Grundlagen der Quantenmechanik [2]. Orthodox Quantum Mechanics (OQM), the version of the theory adopted by the overwhelming majority of physicists, is based on these formalisms. OQM is sometimes referred to as the Copenhagen Interpretation.

In OQM (i) the state vector $|\psi\rangle$ (wave function ψ) completely describes the state of an individual system, and (ii) the evolution of $|\psi\rangle$ is governed by the Schrödinger equation. The exception lies in measurement processes, ruled by the projection postulate [3, pp. 5–6]. *The projection postulate applies only in cases where measurements are performed*. The fact that the Schrödinger equation does not account for collapses (projections, reductions, quantum jumps) resulting from measurements is at the very heart of the measurement problem.

OQM imposes two laws of change to $|\psi\rangle$ and no way to reduce one to the other. But the precise conditions under which each of these laws applies lack definition. John Bell puts it this way: "during 'measurement' the linear Schrödinger evolution is suspended and an ill-defined 'wave function collapse' takes over. There is nothing in the mathematics… to tell which natural processes have the special status of 'measurements.' Discretion and good taste, born from experience, allows us to use quantum theory with marvelous success, despite the ambiguity of

the concepts named above in quotation marks" [4, p. 160]. Bell suggests that *OQM is an ambiguous theory*.

TDPT plays a paramount role in OQM as well as in quantum electrodynamics, the extension of OQM accounting for the interactions between matter and radiation; see for instance [1, Chapter X; 5, Chapter 9]. Without TDPT, OQM would hardly be such powerful and successful a theory. Nevertheless, a critical review of TDPT makes it unavoidable to conclude that *OQM is incoherent* [6].

The contents of this paper are as follows: In Section 2, we sum up TDPT and show that in its framework transitions BSS require measurements. In Section 3 we point out the difficulties encountered by the notion that TDPT gives an account for transitions BSS. In Section 4, we conclude with a possible solution to this problem.

TDPT AND TRANSITIONS BSS

TDPT provides the tools to calculate the probability of transitions BSS induced by a perturbation during a given time interval. TDPT was introduced by Dirac in the following terms: "In [TDPT]… *we suppose* that the perturbed system… is continually changing from one to another [eigenstate of the unperturbed system] or *making transitions*, under the influence of the perturbation" [1, p. 167; emphases added]. He asserts: "[TDPT must] be used for solving all problems involving a consideration of time…" [1, p. 168]. And Walter Heitler adds: "For all problems of physical interest the application of [TDPT] is beyond doubt" [7, p. 138].

TDPT splits in two the total Hamiltonian H(t) acting on the system:

$$H(t) = E + W(t) \qquad (1)$$

where E is the Hamiltonian of an unperturbed system, which can be dealt with exactly. Every dependence on time is included in W(t). Dirac says that "the perturbing energy W(t) can be an *arbitrary* function of the time" [1, p. 172; emphasis added]. The eigenvalue equations of E are

$$E\,|\varphi_n\rangle = E_n\,|\varphi_n\rangle \qquad (2)$$

where E_n (n = 1, 2, …, N) are the eigenvalues of E and $|\varphi_n\rangle$ the corresponding eigenvectors. For simplicity we shall consider the spectrum of E to be entirely discrete and non-degenerate. All the E_n and $|\varphi_n\rangle$ are supposed to be known.

Dirac highlights: "when one makes an observation on the dynamical system, the state of the system gets changed in an unpredictable way, but in between observations causality applies, in quantum mechanics as in classical mechanics, and the system is governed by equations of motion which make the state at one time [$|\psi(t_0)\rangle$] determine the state at a later time [$|\psi(t)\rangle$]. These equations of motion… will apply so long as the dynamical system is left undisturbed by any observation or similar process…" [1, p. 108]. Let $|\psi(t)\rangle$ be the state of the system at time t. If during the time interval (t_0, t_m) the state $|\psi(t)\rangle$ evolves in accordance with the Schrödinger equation

$$i\hbar \frac{d}{dt}|\psi(t)\rangle = H(t)|\psi(t)\rangle \qquad (3)$$

where ħ is the Planck constant divided by 2π and i the imaginary unit, the solution $|\psi(t)\rangle$, which corresponds to the initial condition $|\psi(t_0)\rangle = |\varphi_i\rangle$, is unique. If there were no perturbation, *i.e.*, if the Hamiltonian were E, the state $|\psi(t_0)\rangle$ would be stationary. But the perturbation causes the state to change. Hence at time t the state of the system will be

$$|\psi(t)\rangle = U_H(t,t_0)|\psi(t_0)\rangle = U_H(t,t_0)|\varphi_i\rangle \quad (4)$$

where $U_H(t,t_0)$ is the evolution operator, a linear operator independent on $|\psi\rangle$ and depending only on H, t, and t_0 [1, p. 109].

Without measurements, the postulates of OQM state that the system evolves in agreement with the Schrödinger equation. To obtain transitions BSS measurements are required. In the words of Albert Messiah: "We suppose that at the initial time t_0 the system is in an eigenstate of E, the state $|\varphi_i\rangle$ say. We wish to calculate the probability that *if a measurement is made* at a later time t_m, the system *will be found* to be in a different eigenstate of E, the state $|\varphi_k\rangle$ say. This quantity, by definition the probability of transition from $|\varphi_i\rangle$ to $|\varphi_k\rangle$, will be denoted by $P_{ik}(t_0,t_m)$" [8, p. 725; emphases added]. Clearly

$$P_{ik}(t_0,t_m) = |\langle\varphi_k|U_H(t_m,t_0)|\varphi_i\rangle|^2 \quad (5)$$

Since the evolution from $|\varphi_i\rangle$ to $|\psi(t_m)\rangle = U_H(t_m,t_0)|\varphi_i\rangle$ is *automatic* (with a probability of 1), $P_{ik}(t_0,t_m)$ coincides with the probability that $|\psi(t_m)\rangle$ collapses to $|\varphi_k\rangle$, as stated by the projection postulate.

With the exception of Messiah, references to measurements are conspicuously absent from the treatment of TDPT [9]. Dirac starts by assuming that at the initial time t_0 the state of the system is $|\varphi_i\rangle$. At time t_m the state of the system is $|\psi(t_m)\rangle = U_H(t_m,t_0)|\psi(t_0)\rangle$ [1, p. 172]. At this point he says: *"The probability of E then having the value E_k* is [given by Eq. (5)]. For $E_k \neq E_i$, $P_{ik}(t_0,t_m)$ is the probability of a transition taking place from $|\varphi_i\rangle$ to $|\varphi_k\rangle$ during the time interval (t_0,t_m), while $P_{ii}(t_0,t_m)$ is the probability of no transition taking place at all. The sum of $P_{ik}(t_0,t_m)$ for all k is, of course, unity" [1, pp. 172-173; emphases added].

What does Dirac mean by "*The probability of E then having the value E_k"?* He provides us with the answer in the following paragraphs: "The expression that an observable 'has a particular value' for a particular state is permissible in quantum mechanics in the special case when a measurement of the observable is certain to lead to the particular value, so that the state is an eigenstate of the observable… In the general case we cannot speak of an observable having a value for a particular state… [but] we can go further and speak of the probability of its having any specified value for the state, meaning *the probability of this specified value being obtained when one makes a measurement of the observable*" [1, pp. 46–47; emphases added]. Messiah fully coincides with Dirac (the author of TDPT): transitions BSS *require measurements* [10].

According to TDPT the perturbation W(t) applied during the interval (t_0, t_m) *as well as the measurement of E at t_m are necessary for the transition $|\varphi_i\rangle \longrightarrow |\varphi_k\rangle$ to occur.* If no measurement takes place, the state of the system evolves in agreement with Eq. (4). The following diagram illustrates the complete process leading the system from the initial stationary state $|\varphi_i\rangle$ to the final stationary state $|\varphi_k\rangle$ with probability $P_{ik}(t_0,t_m)$ given by Eq. (5) [6]:

$$|\psi(t_0)\rangle = |\varphi_i\rangle \longrightarrow |\psi(t_m)\rangle \longrightarrow |\varphi_k\rangle$$

First stage	Second stage
during the time interval (t_0, t_m) the Schrödinger evolution leads $\|\psi(t_0)\rangle = \|\varphi_i\rangle$ to $\|\psi(t_m)\rangle = U_H(t_m,t_0)\|\varphi_i\rangle$	$\|\psi(t_m)\rangle$ jumps to $\|\varphi_k\rangle$

It is often overlooked that TDPT requires a measurement in order to obtain the collapse $|\psi(t_m)\rangle \longrightarrow |\varphi_k\rangle$, suggesting that transitions BSS are simply the result of perturbations [6]. A perturbation is something completely different from a measurement. When the perturbation W(t) is applied, the Hamiltonian changes from E to E + W(t), but the Schrödinger evolution is not suspended. By contrast, a measurement interrupts the Schrödinger evolution [1, p. 108].

DOES TDPT ACCCOUNT FOR TRANSITIONS BSS?

Measurements of physical quantities such as position, energy, a component of the angular momentum, etc., will be called usual measurements. The Schrödinger equation accounts neither for collapses resulting from usual measurements nor for collapses resulting from measurements required by TDPT; in both cases the Schrödinger evolution breaks down. Nevertheless, while there is ample reference to the usual measurement problem, the TDPT measurement problem is conspicuously absent from the specialized literature on the subject.

Certainly, the evolution $|\varphi_i\rangle \longrightarrow |\psi(t_m)\rangle = U_H(t_m,t_0)|\varphi_i\rangle$ is induced by the application of the perturbation W(t) during the time interval (t_0,t_m). By contrast, the projection $|\psi(t_m)\rangle \longrightarrow |\varphi_k\rangle$ has nothing to do with W(t). As long as $|\psi(t_m)\rangle$ is not modified, either changing or suppressing the perturbation at t_m has no effect on the whole process of transition between $|\varphi_i\rangle$ and $|\varphi_k\rangle$. If a measurement is performed at t_m the state $|\psi(t_m)\rangle = U_H(t_m,t_0)|\varphi_i\rangle$ jumps to an eigenstate of E whatever the perturbation $W(t_m)$ be.

In usual measurements, the experimenter chooses the physical quantity to be measured. By contrast, in TDPT measurements the experimenter has no choice, *only the measurement of the unperturbed Hamiltonian E matters* [10]. Note that transitions BSS induced by the time dependent perturbation W(t) require a measurement of the energy of the unperturbed system E.

TDPT is of paramount importance to account for absorption and emission of radiation, which are particular cases of transitions BSS; see *e.g.* [1, Chapter VII; 5, Chapter 9]: according to TDPT every photon absorbed or emitted involves a transition BSS and so a measurement. TDPT also applies in processes such as radioactive decay and chemical reactions, as well as in every natural process depending on time being a particular case of transitions BSS. All of them imply measurements. Since according to OQM there are no measurements without observers and/or measuring devices, *there should be billions of observers and/or measuring devices everywhere, at every small corner of the universe where transitions BSS take place*.

Bell ridicules the supposedly necessary intervention of an observer to cause projections when he asks: “What exactly qualifies some physical system to play the role of ‘measurer’? Was the wave function of the world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer, for some better qualified system... with a PhD? If the theory is to apply to anything but highly idealized laboratory operations, are we not obliged to admit that more or less ‘measurement-like’ processes are going on all the time, more or less everywhere? Do we have jumping all the time?” [4, p. 209].

We ask: Where are these billions of observers and/or measuring devices necessary to yield transitions BSS? There is no evidence of their existence, but *transition BSS do occur*. Since the existence of these observers and/or measuring devices is questionable, the same is true of TDPT measurements.

TDPT does not account for transitions BSS. Transitions BSS are the result of causes other than TDPT measurements. Transitions BSS are more or less 'measurement-like' processes going on all the time, more or less everywhere. We do have jumping all the time.

CONCLUSIONS

Quantum weirdness has been traditionally associated with the measurement problem. To solve it, different authors have suggested several strategies. Among them, Statistical interpretation of Quantum Mechanics [11], Bohmian Mechanics [12-13], Bell's Beables for quantum field theory [14], Sudbery's preferred observables [15], Many worlds interpretation [16], Consistent histories approach [17-18], Decoherence [19] and Continuous spontaneous localization theory [20]; the list is not exhaustive. We have addressed these and other proposed solutions to the measurement problem in previous papers [21-24]. Valuable as they may be, these contributions do not solve the traditional measurement problem, let alone TDPT measurement problem not even mentioned in these contributions.

OQM weirdness is far from limited to the measurement problem. It is much more serious and justifies a radical revision of the theory [6]. According to the starting point of the solution we propose, *two kinds of processes irreducible to one another occur in nature: the strictly continuous and causal governed by a deterministic law, and those implying discontinuities, ruled by probability laws* [9, 21]. In the Spontaneous Projection Approach, a version of quantum mechanics based on this hypothesis, the tendency of the system to jump to the eigenstates of the constants of the motion plays a paramount role [9]. Spontaneous Projection Approach yields the same experimental predictions that OQM, with few exceptions. These exceptions could be exploited to test the validity of the proposed theory [24].

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