Particle creation as the quantum condition for probabilistic events to occur

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Abstract
A new version of non-relativistic quantum theory is proposed, according to which probabilistic events occur whenever new stationary or bound states are created as a result of inelastic collisions. The new theory recovers the experimental success of orthodox quantum theory, but differs from the orthodox theory for as yet unperformed experiments.

1. Introduction

Orthodox quantum theory (OQT) fails to specify the precise nature of quantum systems, such as electrons and atoms, as they exist in space and time, due to a failure to solve the quantum wave/particle problem. As a result, OQT is obliged to be a theory, not about quantum systems per se, but rather about quantum systems undergoing measurement. This means that the purely quantum mechanical postulates of OQT are without physical content; it is only when some part of classical physics is adjoined to these postulates, so that the process of measurement may be described, that OQT becomes a *physical* theory. As a result of being made up of these two conceptually incoherent parts (quantal and classical), OQT is, despite its immense empirical success, a seriously defective theory. It is imprecise, ambiguous, ad hoc, non-explanatory, restricted in scope, and resistant to unification [1-7]. In order to develop a version of quantum theory (QT) free of these defects, it is necessary to solve the wave/particle problem, thus providing a consistent model of quantum systems as they are in space and time independent of measurement, and freeing QT of its present conceptual dependence on classical physics.

Elsewhere [3-5] I have proposed the following solution to the wave/particle problem. The quantum domain is fundamentally probabilistic in character. The physical states of quantum systems evolve deterministically, in a quasi wave-like manner, in accordance with the Schrödinger equation: what evolves, however, are propensities to interact in a probabilistic and quasi particle-like manner with other quantum systems, should appropriate quantum physical conditions to do so arise. (The notion of "propensity" employed here, a modification of Popper's notion [8,9], is a probabilistic generalization of the deterministic notion of physical property associated with classical physics [3,5,10].) Because quantum systems are inherently *probabilistic* physical entities, they differ fundamentally from all *deterministic* physical entities encountered in classical physics, such as the classical panicle, wave or field. The wave-like and particle-like features of quantum systems are precisely the kind of features one would expect such systems to possess, granted that they are fundamentally probabilistic entities. Electrons, protons and atoms are neither waves nor particles: they are *propensitons* - physical entities with evolving propensities as basic properties, which determine how the entities interact with one another probabilistically. The nature of quantum systems only remains a mystery as long as we persist in the misguided attempt to understand them as deterministic entities. Acknowledge their inherently *probabilistic* nature, and quantum systems can be seen to behave just as good, descent probabilistic entities should behave. On this view, OQT is a defective theory because its creators failed to acknowledge adequately the fundamentally probabilistic character of the quantum domain, and thus failed to develop QT as a fully realistic theory about inherently probabilistic quantum "beables".

This proposed solution to the wave/particle dilemma requires that precise quantum mechanical conditions are specified for probabilistic transitions to occur, conditions which restrict the application of the (deterministic) Schrödinger equation, but which make no reference to measurement (as in the case of OQT). A number of different proposals have been put forward for quantum conditions for probabilistic events to occur [11-16]. My proposal, here, is that probabilistic transitions occur when and only when new stationary or bound states, new "particle" states, are created as a result of inelastic collisions [4,5]. However, in comparison with the version of QT put forward by Ghirardi et al. [16], my proposal has so far suffered from being somewhat imprecise [17]. I now formulate the idea precisely.

2. Precise formulation of quantum condition for probabilistic wave-packet-collapse

Consider a rearrangement collision, with a two channel outcome,

$$(ab) + c \;\rightarrow\; \begin{cases} (ab) + c & (A) \\ a + b + c & (B) \end{cases} \qquad (1)$$

Here, a, b and c are spinless particles and (ab) is the bound state. According to OQT, the outcome of the interaction is a superposition of the two channel states, (A) and (B); only on measurement, is *either* (A) *or* (B) detected. But according to the propensiton version of QT being proposed here (PQT), the superposition of (A) and (B) collapses spontaneously and probabilistically into either (A) or (B), even in the absence of measurement. Indeed, according to PQT, all probabilistic quantum measurements are just physically unremarkable special cases of this kind of probabilistic transition. All such measurements, that detect quantum systems, do so by the creation of new stationary or bound states, by the ionization or dissociation of molecules, for example: it is this which ensures that probabilistic transitions occur.

More precisely, the probabilistic collapse occurs when the interaction responsible for the inelastic part of the collision is very nearly at an end. Let the state of the entire system be $\psi(t)$, and let the asymptotic states of the two channels (A) and (B) be $\psi_A(t)$ and $\psi_B(t)$, respectively, so that, according to OQT, there are states $\varphi_A(t)$ and $\varphi_B(t)$ such that as $t \rightarrow \infty$

$$\varphi_A(t) \rightarrow \psi_A(t), \quad \varphi_B(t) \rightarrow \psi_B(t)\,, \qquad (2a)$$

and for all t,

$\psi(t) = c_A \varphi_A(t) + c_B \varphi_B(t)$, (2b)

with $|c_A|^2 + |c_B|^2 = 1$.

Here, the evolutions of $\psi_A(t)$ and $\psi_B(t)$ are governed by the respective channel Hamiltonians, H_A and H_B, respectively. These differ from the Hamiltonian, H, governing the evolution of $\psi(t)$, $\varphi_A(t)$ and $\varphi_B(t)$, in that forces between particles that are not in bound states are set to zero. We have

$$H = -(T_a + T_b + T_c) + V_{ab} + V_{ac} + V_{bc} \, , \tag{3}$$
$$H_A = -(T_a + T_b + T_c) + V_{ab} \, , \tag{4}$$
$$H_B = -(T_a + T_b + T_c) \, . \tag{5}$$

Here, T_a, T_b, T_c represent kinetic energy, so that $T_a = (h^2/2m_a)\nabla^2$, where m_a is the mass of particle a. V_{ab}, V_{ac} and V_{bc} are potentials corresponding to the forces between a and b, a and c, and b and c, respectively.

The condition for probabilistic collapse can now be stated as follows.
Let $\psi^c(t) = c_A\psi_A(t) + c_B\psi_B(t)$. Then:

Condition 1. At the first instant t for which $| \langle \psi^c(t)| \psi(t) \rangle| > 1 - \varepsilon$ is satisfied, the state of the system, $\psi(t)$, jumps probabilistically into either $\varphi_A(t)$ with probability $|c_A|^2$ or into $\varphi_B(t)$ with probability $|c_B|^2$, ε being a universal constant, a positive real number very nearly equal to zero.

It is a straightforward matter to generalize condition 1 so that it applies to the case of an inelastic interaction with N channel outcomes, with N distinct asymptotic states, N > 2.

Detection of a micro system as a part of the process of quantum measurement typically involves allowing an unlocalized system to interact elastically with billions of localized systems, as when a photon interacts with the billions of silver bromide crystals of a photographic plate. In this sort of case, the generalized version of condition 1 is to be straightforwardly applied. The outcome of the interaction is a superposition of billions of channels; these collapse to just one or other channel when condition l is satisfied. The outcome is the dissociation of one silver bromide molecule somewhere on the photographic plate.

Granted condition 1, inelastic interactions can, but do not invariably, localize. In the case of inelastic scattering of neutrons by means of a crystal lattice, although the neutrons interact inelastically with the crystal lattice, they are not localized at one or other node of the lattice, as is demonstrated by the existence of interference effects in the scattered neutron beam. The inelastic interaction creates an unlocalized phonon in the crystal. In this case, there are just two channel outcomes: the outcome of the elastic interaction, and the inelastic interaction.

3. Experimental adequacy of PQT

It might be thought that PQT cannot recover all the empirical success of OQT. OQT includes the following:

Postulate I. If a measurement of observable A is performed on a system in a state ψ, then the probability of obtaining a value between a_r and a_{r+dr} = $|(\alpha_r, \psi)|^2$ dr, where a_r, and α_r are eigenvalues and eigenvectors of the Hermitian operator Ă corresponding to the observable A.

PQT differs from OQT in that it dispenses with postulate 1, and replaces it with the generalized version of condition 1. PQT is thus restricted to making probabilistic predictions about the outcome of inelastic collisions. This means, on the face of it, that PQT is restricted to making predictions about *position* measurements - position, typically, being measured via ionization or dissociation of molecules. How can PQT make predictions about other observables, energy, momentum, spin?

The answer is that all measurements, of all observables, that are not merely *preparations* (to use Margenau's term [18]), involve the *detection* of quantum systems via the creation of new bound states. For example, a measurement of energy or spin involves, typically, a preparation procedure, which associates distinct spatial regions with eigenstates of energy or spin, plus *detection* of systems in one or another spatial region (see Ref. [3], pp. 661-666; Ref. [4], pp. 622-626; and Ref. [5], pp. 35-37). PQT is thus able to reproduce all the empirical success of OQT without calling upon postulate I. In particular, whereas OQT must *presuppose* the existence of quasi classical macro objects, for measurement, PQT is able to *predict* the existence of such objects from purely quantal postulates. A macro object remains localized because it repeatedly suffers probabilistic localizations, in accordance with condition 1.

In opposition to what has just been claimed, it may be argued that some measurements need only involve elastic collisions, in which case, according to condition 1, no probabilistic collapse will occur. This may, indeed, be thought to provide sufficient grounds for rejecting condition 1, and the version of PQT based on it. Consider, for example, the following thought experiment (suggested by an anonymous referee), intended to illustrate the general idea of measurement without inelastic collision. A massive particle is scattered elastically into two wavepackets, each ending up in distinct pans of a balance. Condition 1 implies that, as long as no inelastic collision occurs, the balance will go into a superposition of weighing the particle in one pan, and in the other pan (which only collapses into one or other state with the eventual occurrence of some random inelastic collision). But this, it may be argued, is absurd, since the balance is a macroscopic object.

But is the idea that such macroscopic superpositions exist absurd? Surely not. According to PQT, the world is made up of propensitons, fundamentally probabilistic objects which, in appropriate conditions, evolve into superpositions of states and, as a result, smear out spatially in a way that is unlike anything encountered in deterministic classical physics.

Composite objects, such as atoms, molecules, crystals and other macroscopic objects are just as much propensitons as electrons are. All this does violence to common sense, and to physical intuitions based on deterministic classical physics; but that does not in itself provide grounds for rejecting the idea that propensitons exist, that even macroscopic objects are propensitons, and superpositions of macroscopically distinct states exist in appropriate circumstances.

Whether a macroscopic balance can exist in the kind of superposition of states indicated above is a *factual* question, the answer to which cannot be decided a priori. In principle it is possible to determine the answer experimentally; in practice this is difficult, due in part to the large mass of macroscopic objects such as the balance, and due in part to the ubiquity of inelastic collisions. (We would never be able to *see* the balance in a superposition of states, since seeing involves the occurrence of inelastic interactions.) The fact that the two-slit experiment can be done with atoms, and presumably with molecules, with tiny crystals, may incline us to the view that interference effects could in principle be detected even if the experiment is done with macroscopic objects (since the difference between micro and macro is here a matter of degree rather than kind).

It is worth noting, finally, in connection with this point, that PQT and OQT agree that superpositions of macroscopically distinct states can exist. However, the version of QT proposed by Ghirardi et al. [16], referred to above, implies that sufficiently large macroscopic objects do not persist in superpositions of macroscopically distinct states, even in the absence of inelastic collisions. There is here, perhaps, the possibility of a crucial experiment capable of deciding between OQT and PQT on the one hand, and the version of QT proposed by Ghirardi et al. on the other hand.

4. Crucial experiment

How can experiment decide between PQT and OQT? As long as ε is sufficiently small to ensure that no probabilistic transitions occur during inelastic collisions in physical experiments until measurements are performed, PQT will accurately reproduce all the predictions of OQT. (The two theories employ the same dynamic laws of evolution.) Indeed, even if probabilistic transitions do occur before measurement, the distinct predictions of OQT and PQT will not ordinarily be detected. In the case of the rearrangement collision, the difference between the *superposition* $c_A\ \varphi_A(t) + c_B\ \varphi_B(t)$, predicted by OQT, and the *mixture* $\varphi_A(t)$ (probability $|c_A|^2$) *or* $\varphi_B(t)$ (probability $|c_B|^2$), predicted by PQT, will not be detected by ordinary experiments.

In order to detect the difference, it will be necessary to recombine the two channels, (ab) + c and a+b+c, so that the a+b+c channel becomes (ab) + c, and interference effects can be detected. This requires that the experimental setup is such that no measurement can determine along which route, (ab) + c or a + b + c, the system evolves. Granted that the value of ε is such that, in these circumstances, PQT predicts that the superposition $c_A\varphi_A(t) + c_B\varphi_B(t)$ collapses into either $\varphi_A(t)$ or $\varphi_B(t)$ (before measurement) then, whereas OQT will predict interference, PQT will predict no interference.

The possibility, in principle, of performing this crucial experiment establishes that OQT and PQT are empirically distinct theories. The crucial experiment is however extremely difficult to do in practice, and has not as yet been performed as far as the present author is aware.

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