What Are Quantum States?

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Abstract. We present three strong arguments against the ontic interpretation of quantum states. We then show that the appropriate alternative is not a naive epistemic interpretation, but viewing quantum states as representing the available knowledge about the potentialities of a quantum system from the perspective a of a particular point in space. Unlike ordinary knowledge, which requires a knower, available knowledge can be assumed to be present regardless of a knower. We proceed to show that the objectivized aspect of Whitehead's actual entities corresponds to the collapse of quantum states. Finally we point out that the negation of the ontic interpretation of quantum states need not lead to a negation of Whitehead's ontic description of actual entities.

1. Arguments against the Ontic Interpretation of Quantum states

Imagine an electron moving towards a TV screen. Where will it hit? We don't know. We can, however, assign probabilities to the potentialities of hitting at different locations. These are given by the so-called “wave function,” or “quantum state.” Once it hits, there is no longer a question of probability. The quantum state “collapses” into the point of impingement.

How does the collapse occur? How does the electron “choose” a place to hit the screen? This so-called “measurement problem” is the great mystery at the heart of quantum mechanics.

The point of this paper is not to solve the measurement problem. Rather, it is to discuss, first, what quantum states are and, second, find the corresponding concept in Whitehead's system, and resolve an apparent discrepancy between Whitehead's system and the understanding of quantum states.

What are quantum states? It is natural to assume that they are an *ontic,* that is, they describe how the system is. The alternative is an *epistemic* interpretation that claims that they describe not the system, but our knowledge about it. The question of which is right turns out to be more subtle and interesting than we expect. Let us begin by presenting

three different arguments against the ontic interpretation.

For the first argument we have to go back some eighty years, to the Fifth Solvey Conference of 1927. The Conference is famous for what happened outside the public lectures: The Einstein challenges to the uncertainty Principle and Bohr's rebuttals. In one of the public sessions, however, Einstein, tacitly assuming the ontic interpretation of the wave function, pointed out that the collapse, which he assumed took place instantaneously, means that the influence of the appearance of an elementary quantum events leads to an instantaneous (faster than light) propagation of the change in the value of the wave function everywhere on the hypersurface.

As on many other occasions, although Einstein began by saying “I must apologize for not having penetrating quantum mechanics deeply enough,”[i] his point was penetrating enough to generate, decades later, a strong objection to the ontic interpretation.

A second and different objection is that the ontic interpretation is incompatible with Einstein's principle of Relativity[ii].

A third objection is to apply common sense to Schrödinger's cat. According to the ontic interpretation the cat is in a state of superposition of being alive and being dead in various proportions that change as time goes by. According to the epistemic interpretation the superposition says nothing about the cat, It speaks about us. It says that we don't know how

the cat is, and, indeed, we don't.

2. Arguments against the Epistemic Interpretation of Quantum states

Shall we adopt, then, the epistemic interpretation? Not so fast. The epistemic interpretation is also objectionable. The objections have to do with the apparent need for a knower. For example: What if the knower is a physicist who had a martini before trying to "know"? What if a person who knows just a little physics learns of the result? What if he had a martini? Somehow we feel that such questions are irrelevant.

3. Quantum States as Perspectives on available Knowledge

To avoid difficulties of this kind regarding the epistemic interpretation, we can consider a quantum state as representing not actual knowledge (which requires a knower), but the available or potential knowledge about a system.

The main difference between being and knowledge has to do with the question. "Where do changes take place?" In the case of knowledge there is no change anywhere, excepting, possibly, at the place of the potential knower. In particular, if there is knowledge *about* something this "something" is not affected at all. Knowledge refers to it; it does not change it.

For example: Suppose I wish to eat an orange and I learn that I can get one in a particular store. This bit of knowledge induces change here, in me, not on the orange I am about to buy or in the store. Only when the knowledge brings about *action* is there change in the world.
The full characterization of quantum states, or wave functions, then, is this: quantum states represent the available knowledge about the potentialities of a quantum systems, knowledge from the perspective of a particular location in space. To void the use of such a long expression we will call it, simply, "perspectives on knowledge." It is important to bear in mind, though, that
the expression "perspectives on knowledge" is a shorthand for "the available knowledge about the potentialities of a quantum system, knowledge from the perspective (of a particular location in space."

4. Actual Entities and the Collapse of Quantum states

Does the acceptance of this version (or any version) of the epistemic interpretation go against Whitehead's ontic descriptions, e. g., the description of actual entities? Let approach this issue by discussing the correspondence between actual entities and quantum states.

Here is a brief summary of the characteristics of actual entities.
(i) Actual entities are neither purely subjects nor

purely objects; they have both subjective and objective characteristics.
(ii) They are short lived, flashing in and out of existence in spacetime. The apparent existence of enduring objects is due to the similarity among collections of actual entities, which replace each other in quick successions.
(iii) Each actual entity is a nexus that can be distinguished from other actual entities in the nexus of relationships to which it belongs.
(iv) An actual entity is the process of its own self-creation. i.e., an actual entity is constituted by *process* that leads to a momentary appearance of an object.
(v) This self-creation involves accommodating and integrating within itself (comprehending or "prehending" in Whitehead's terminology) all the previous actual entities as "settled facts" that cannot be changed, and all anticipations of the future actual entities. This process of self-creation involves a sequence of phases, which are delineated and analyzed in detail in Whitehead's Magnum Opus, *Process and Reality.*

An example: Listening to an orchestra playing a symphony involves, at each moment, accommodating the sounds produced by the orchestra. This accommodation depends, in turn, on many collections of past actual entities, such as previous knowledge and training in music, associations with the symphony, etc. Notice that at each instant there is *one experience.*

This example is special, because it involves human cognition. In general, this need not be the case. There can be experiencing without cognition, e.g., driving “on automatic pilot.”

(vi) The end product of the process is *one* new actual entity, one “throb of experience”. The fundamental building blocks of the universe are, then, events based on such elementary forms of experience. We live not in “a universe of objects,” but in “an experiential universe of events (or universe of experience-based events?).” This is an enormously significant paradigm shift.

(vii) Subjectively, i.e., for itself, an actual entity is “a pulse of experience”. The end of the process of self creation is called “the satisfaction of the actual entity”. Although its subjective existence is momentary, objectively, i.e., for other, future actual entities, it is “a settled fact”: The fact that it did happen cannot be erased. “The end of . . .[its] private life-its 'perishing,'-is the beginning of its public career.”

(viii) The *process of self-creation of* an *actual entity is not* a *process in time; it is, rather,* an *atemporal process leading* to *the momentary appearance of the completed actual entity in spacetime.* Quoting Whitehead: “[In the process of self-creation which is an actual entity] the genetic passage from phase to

phase is not in physical time...the genetic process is not the temporal succession...Each phase in the genetic process presupposes the entire quantum."[iii]

Examples of atemporal processes:

1. The creation of time in Plato's *Timaeus* comes after many other acts of creation - all of these must be atemporal.

2. The Platonic "participation" of the Forms in sensible things is another example of atemporal processes.

3. Whitehead's thinking was Platonic, yet his precision was a mathematician's. Therefore his inclusion of atemporal processes in his system is significant.

How does the idea of an actual entity fit with quantum mechanics (QM) ?

As we know, QM is plagues with different interpretations. If we take the Heisenberg' mainstream interpretation, then reality is constituted from fields of potentialities punctuated by "elementary quantum events." As we mentioned before, the process that leads to the creation of elementary quantum events is called "the collapse of the quantum state." It appears that such collapse is the atemporal process that corresponds to an actual entity, and the elementary quantum event

corresponds to what Whitehead called “the satisfaction of an actual entity”.

Well, these correspondences work, but only up to a point. To understand why, we have to turn Erwin Schrödinger. When I recently discussed with Abner Shimony the role of the great physicists as philosophers, he said that Schrödinger is “in a class by himself.”

According to Schrödinger, science, as it is practiced now, is based on two principles. First, the belief that nature is comprehensible, and, second, the principle of objectivation.

“By this [i.e., by “the principle of objectivation”) I mean what is also frequently called the ‘hypothesis of the real world’ around us. I maintain that it amounts to a certain simplification, which we adopt in order to master the infinitely intricate problem of nature. without being aware of it and without being rigorously systematic about it, we exclude the Subject of Cognizance from the domain of nature that we endeavor to understand. We step with our own person back into the part of an onlooker who does not belong to the world, which by this very procedure becomes an objective world.”

Schrödinger's principle of objectivation corresponds to Whitehead's “fallacy of misplaced concreteness”.

The problem with the correspondence of the collapse to an actual entity is that QM, as a part of our science, is subject to the principle of objectivation. The collapse, as it is now understood, has nothing subjective about it. An actual entity, however, has both a subjective aspect and an objective aspect.

The main conclusion I am driving to is this: **The collapse corresponds to an actual entity to the extent that science would allow it to; i.e., it corresponds to the objective aspects of an actual entity.**

When one follows, point by point, the characteristics of actual entities mentioned above, one is amazed to what extent one can think of collapse as an objectivized actual entity.

This becomes all the more remarkable when we remember that Whitehead created his system in the 1920's, knowing only the old QM of Bohr and Einstein, and not the mature QM of Heisenberg and Schrödinger.

5. Ontic Description and Epistemic Interpretation

We finally have all the ingredients needed to resolve the issue of whether there is a contradiction between the ontic descriptions of Whitehead and the epistemic interpretation of quantum states.

As we have seen, quantum states are a way of

mathematically expressing the available knowledge about a quantum system from the perspective of a given point in space. On the other hand, Whitehead's description is, by his own admission, “speculative”. While admiring the beauty and coherence of his system, we should not lose sight of the fact that it does go behind the physical evidence by making ontic claims.

In short, the epistemic interpretation of quantum states and Whitehead's ontic description are both valid within their different domains of reference. Since they refer to different domains, there is no contradiction between them.

References

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i A. Pais, *“Subtle Is the Lord...”* Oxford Univ. Press, 1982, p. 445. .

[ii] As Aharonov and Albert proved, [Y. Aharonov and D. Z. Albert, *Phys. Rev.* **D21,** 3316 (1980)]; *Phys. Rev.* **D24,** 359 (1981)] the collapse takes place, indeed, on t=const. hypersurface. And, as I have shown some twenty years ago, this leads to the conclusion, that if in a given (unprimed) frame of reference the collapse takes place on t=const. hypersurface, then in another (primed) frame that is moving relative to the first, it cannot take place on a t’=const. hypersurface [S. Malin, *Phys. Rev.* **D36,** 1330 (1982);

Found. Phys. **14,**1083 (1984)]

iii A. N. Whitehead, *Process and Reality,* corrected edition, D. R. Griffin and W. Shelburne, eds., the Free Press, New York, 1978, p. 283.