Ontology and the Wave Function Collapse

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Abstract

This paper makes a case for ontology, the study of existence, to be explicitly and formally incorporated into foundational physics in general and the wave function collapse of quantum mechanics in particular. It introduces a purely ontological distinction between two modes of physical existence-actualizable and actual- into the conventional mathematical representation of the wave function collapse, and examines the implications of doing so, arguing that this may lead to insights that permit one to understand seemingly mysterious aspects of the wave function collapse, such as 'Schrödinger's cat paradox', as well as how quantum theory in general and Einstein's general theory of relativity relate to one another. A specific empirical prediction is given, which if confirmed, may move ontology outside the exclusive purview of philosophy.

Keywords: Philosophy of Quantum Mechanics, Interpretation of Quantum Mechanics, Measurement Problem, Wave Function Collapse, Ontology, Actual Existence, Actualizable Existence, Domain of Validity

1 Ontology in Foundational Physics

It has been said that philosophy is what remains after all areas of study that used to be part of it have formed their own distinct fields [1]. One area of study which has so far steadfastly remained with philosophy is ontology, the study of 'being in general, embracing such issues as the nature of existence and the categorical structure of reality'[2, p. 670]. If one considers how deeply our most fundamental physical theories of nature, quantum theory and relativity, delve into questions about the nature of reality, it seems surprising that ontology does not usually appear to play an explicit role in these areas of physics, except on those occasions on which a philosopher like Albert, say, exclaims that quantum field theory changes the 'fundamental ontology of the world'[3, p. 59].

Yet, it can be argued that ontological dimensions lurk behind our fundamental theories pervasively, if one only looks for them. For instance, according to the special theory of relativity, observers stationary relative to one another will measure the time in the rest frame of an entity moving relative to them i.e. its proper time, to pass more slowly relative to their own i.e. the coordinate time (assuming appropriate synchronization procedures), and the faster the entity moves, the shorter its proper time is observed to be [4, p. 60 ff.]. If the entity moves at the speed of light, its proper time is observed to be exactly zero. But this implies that any entity which moves at the speed of light from the time it comes into existence until it ceases to exist must be observed to perceive itself to have a zero duration of existence in spacetime (since no time passed in its rest frame and presumably it is at rest with respect to itself). This seems very strange, as one might intuitively have thought that a zero duration of existence would be associated with non-existence, but such entities, e.g. photons, clearly exist. This has been previously pointed out by this author and termed the *existence paradox*[5].

Is drawing attention to this just idle philosophizing? Consider that once this is realized, *and it is accepted*

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that such entities and their associated frames are ontologically distinct, and thereby mutually exclusive, from ordinary spacetime observers and their frames, one can immediately deduce, only supposing that any frame associated with motion in space at the speed of light can be shared with some photon proper frame, that no ordinary observer in spacetime can be accelerated to the speed of light[1] : By definition, such an observer will already have perceived a finite duration of existence in spacetime for himself. If he could be accelerated to the speed of light, then this would lead to a contradiction on ontological grounds because he would then be in a rest frame belonging to those ontologically distinct entities. Special Relativity would then be simply wrong. Compare this to the standard physics explanation which says that ordinary observers cannot be accelerated to the speed of light because doing so would require an infinite force and infinite energy, and notice how much simpler (since the chain of reasoning is more direct) and more intuitive (since it avoids recourse to infinite quantities) the ontological explanation is. The point of this example is to illustrate that seriously and directly incorporating ontology into physics may simplify and even deepen our fundamental understanding of nature. The main purpose of this paper is to show that the so-called wave-function collapse may well present another instance in which an explicit consideration of ontology may illuminate a fundamental problem in physics, thereby strenghtening the case for its formal incorporation into our most fundamental theories of nature.

2 A Brief Review of the Wave-Function Collapse

According to the standard formulation of non-relativistic quantum mechanics, a physical system is describable in terms of a so-called state vector $|\Psi>$ in a special type of vector space called a Hilbert space [6, p.115 ff.]. This state vector can be decomposed into (usually) an infinite number of basis vectors $|\psi_i>$, where the index is meant to distinguish each basis vector from all others. Less abstractly, each basis vector represents one possible outcome of the measurement of a particular property of the system.
Mathematically, the definition of a basis vector requires it to be linearly independent from all other basis vectors, which translates into the physical fact that each possible measurement outcome is incompatible with all others. When no property of the system is measured, the system evolves according to Schrödinger's equation and its description can thereby be predicted arbitrarily far into the future, but when a measurement is performed, the system is always found to be in a state described by one and only one of the basis vectors (in the basis that encompasses the possible outcomes of that particular measurement). In symbols, this process is conventionally depicted as follows:

$$|\Psi> \xrightarrow{'Measurement'} |\psi_i> \tag{1}$$

Where both vectors are assumed to be normalized. The term *measurement problem* labels the mysterious fact that this does not seem to be consistent with the system's time-evolution according to Schrödinger's equation. If it were consistent, the outcome of the measurement should have yielded the state vector predicted by Schrödinger's equation, but instead it yields a basis vector with a probability proportional to the square of a coefficient that determines its contribution to the state vector. That the system immediately prior to measurement must have been represented by the state and not the basis vector, however, is demonstrated by empirical tests such as the Stern-Gerlach and double-slit experiments.
The attempts to address the measurement problem can be grouped into two main categories: Those which postulate that the 'measurement' (whatever may be meant by it) produces a 'reduction' of the state vector

[1] Proof:
P1: Every proper frame associated with motion in space at c can be shared with some photon proper frame
P2: Photon proper frames are ontologically distinct from those of ordinary spacetime observers
P3: Ontologically distinct frames cannot be shared with one another (This is part of what the ontological distinction entails)
1: Suppose that it is possible to accelerate an ordinary spacetime observer to motion in space at c, then
1a: the spacetime observer's proper frame is associated with motion at c (by 1), and
1b: the spacetime observer's proper frame can be shared with some photon proper frame (by P1 and 1a), but
1c: Proper frames of ordinary Spacetime observers cannot be shared with proper frames of photons (by P2 and P3), so
2: If an ordinary spacetime observer can be accelerated to c he can and cannot share a proper frame with some photon (by 1b and 1c)
C: An ordinary spacetime observer cannot be accelerated to motion in space at c (by contradiction in 2)
Note that from a purely logical perspective, P2 and P3 can be combined into one premise P'2 by eliminating the concept of an ontological distinction, but then one also eliminates the clue provided by the curious ontological state of photons which could hint at deeper insights

into one of its basis vectors, and those which do not postulate such a reduction. In this paper, we will only be concerned with the former.
The reduction of the state vector is more commonly called the *wave-function collapse*, since the state vector can equivalently but more intuitively be expressed as a wave function, as it satisfies a wave equation, which here is just Schrödinger's equation.
The wave function collapse postulate presents a scientific and philosophical conundrum because a) unlike any other fundamental axiom of physics it seems to make the observer an integral part of the description of reality, b) it is vague in that it does not precisely tell us what 'measurements' or 'observers' are and c) it is physically unsatisfying because it does not tell us what sort of physical process it really describes.
Let us now examine how formally incorporating ontological concepts into quantum mechanics may yield an approach to understanding this conundrum.

3 Introducing an Ontological Distinction

Based on Equation (1) quantum mechanics with wave function collapse ostensibly makes no assumptions about the ontological status of states before and after measurement, since it does not specify anything in that regard. But the absence of specification itself implies an assumption, namely that the states before and after are ontologically on an equal footing.
How can we evaluate whether this implicit assumption should be believed? If we take the possibility of a system existing in a superposition of states in a particular basis as a criterion, then the fact that immediately prior to a measurement a system can and most often does exist in a superposition (except when it had just been measured) whereas immediately after a measurement it absolutely never exists in a superposition (in the same basis) suggests that the evidence in favor of this assumption is weak. On the contrary, it suggests that ontologically the state describing the system immediately prior to a measurement is somehow different from that describing the system immediately thereafter.
Let us introduce terminology to label this distinction: Call states prior to a measurement *actualizable* and states immediately after a measurement *actual*. The term 'actualizable' means 'capable of becoming actual'. Hence, on this account there are two distinct modes of physical existence, and the wave function collapse can be thought of as the transformation from a linear superposition of actualizable states to a single actual one. The distinction can be captured notationally by modifying equation (1) to

$$|\Psi > \xrightarrow{'Measurement'} |\underline{\psi}_i > \tag{2}$$

Here, underlining a vector means that it represents a system in an actual state, otherwise the vector represents an actualizable state. In other words, *the default modes of existence in quantum theory are represented by actualizable, not actual, states*. Obviously, this change is mathematically trivial because it does not alter the mathematical content of standard quantum mechanics. But this very fact ensures that any predictions coming out of this changed framework are always consistent with standard quantum mechanics.
Philosophically, on the other hand, this appears to break new ground because it presents, to this author's knowledge, the first instance in which purely ontological concepts are formally incorporated into the equations of physics. Let us now see what is to be gained from introducing this distinction.

4 Implications of the Ontological Distinction

Re-examining the problems with the wave function collapse mentioned above, we find that, in light of this novel ontological distinction, the observer is now essentially reduced to 'something' that initiates the mechanism by which the mode of existence of the quantum system is transformed from actualizable to actual, where our current name for this mechanism is, of course, a 'measurement'.
But what is this mechanism, really? If this re-interpretation were merely an exercise in re-naming vague quantum mechanical terms, then one would gain nothing from it. But notice that already, even without knowing what physical processes these terms entail, there is a shift in emphasis away from the anthropomorphic connotations inherent in standard quantum mechanics with wave function collapse toward the transformation of the quantum system itself. And, if the absence of the observer the description of reality in the rest of

physics is any guide, this is really the first step necessary to demystify the physical process behind the wave function collapse.
We can connect this with the curious ontological state of photons, which was pointed out in section 1, since photons, after all, are purely quantum objects. Evidently, putting the photon's existence paradox together with this novel ontological distinction, and considering the fact that photons always cease to exist when they are 'measured', all suggest that the existence of photons in particular and of objects with zero proper time in general in spacetime is exclusively actualizable.
On the other hand, electrons or other massive quantum objects can, under this interpretation, exist either actualizably or actually in spacetime, depending on whether their wave function has 'collapsed'. The fact that very soon after having 'collapsed', it reverts to obeying Schrödinger's equation (which implies that, once again, it is an actualizable state) whereas macroscopic system states are not observed to ever obey it suggests, admittedly in an imprecise manner, that the transition from microscopic objects, such as electrons, to macroscopic objects, such as cats, say, not only involves a change in size but also a change in the amount of time spent in a particular mode of existence: Whereas the former exist most of the time actualizably in spacetime, the latter exist essentially always actually in spacetime. This allows us to think of certain problems, such as the well-known 'Schrödinger's cat paradox', as arising from a neglect of the consideration that the ontological status of 'classical' objects, such as cats, renders the rules of quantum mechanics inapplicable to them. What is meant here is that for any object for which we phenomenologically fail to observe quantum behavior, we can attribute this to its ontological state. Thus, since objects much smaller than cats (but much larger than electrons), are known to behave purely classically (under ordinary conditions), this distinction allows us to restrict the applicability of the rules further down to a regime close to that of the atom positioned to start the chain reaction, presumably beyond which the system will at some point permanently remain in an actual mode of existence.
Furthermore, taking this to be the missing factor in the transition from quantum to classical physics allows us to point out another novel fundamental distinction: According to our best current understanding of quantum theory and Einstein's general theory of relativity, the two appear to be in some very fundamental aspects mutually incompatible. For instance, whereas the state vector is an essential component of the former, and one which introduces many of the theory's unfamiliar aspects, it is completely absent in the latter. General relativity has, to be sure, its own unfamiliar conceptual aspects, most notably the idea that gravity is a manifestation of spacetime curvature, but these are of a completely different nature than those found in quantum theory [4, p. 445 ff.].
Equation (2), in conjunction with the idea that quantum objects differ from classical ones not only generally in size but, more importantly, in their mode of existence (at least most of the time), allows us to carve out domains of validity for these two theories in such a way that whenever they seem to clash with one another, one of the two can be found to be outside its own domain. More concretely, according to this interpretation one can broadly think of the quantum theories (and here we mean to include the quantum field theories) as the physical description by spacetime observers of objects which actualizably exist in spacetime but whose ontological states can under certain conditions (yet to be specified) be transformed into ones that actually exist in spacetime, whereas general relativity can be understood as the physical theory exclusively concerned with the description by spacetime observers of objects that already enjoy actual existence in spacetime. In both theories, 'spacetime observers' themselves are assumed to actually exist in spacetime.
This, in turn, suggests a definite prediction which is at least in principle testable, thereby moving this whole business of formally incorporating ontology into physics beyond the realm of metaphysical speculation to scientific hypothesis: If the wave function collapse demarcates the boundary between the domains of the two theories, then the gravitational field of any quantum system (i.e. any system describable by a state vector that evolves according to Schrödinger's equation) must be precisely zero, since it is only through the collapse that the system actually exists in spacetime and therefore falls within the domain of general relativity, which is a theory of gravity, after all. And this, finally, implies that there is a tight connection, possibly even an *identity*, between the wave function collapse and the creation of a gravitational field.
It seems, then, that even without having identified the specific physical process behind equation (2), the novel distinction introduced here suggests new ways of thinking in terms that are far more general than just that single aspect of quantum mechanics we call the wave function collapse.
It should be emphasized that, like any novel scientific idea, it also raises many new questions. Here are some:

- Why would nature favor two distinct modes of existence over just one?

- How and why does a quantum object like an electron revert back from an actual state to an actualizable one?
- Given that the basis state $|\psi_i>$ is a superposition state in some other basis, how can the distinction between actualizable and actual states be understood more deeply?
- How can the potential internal inconsistency of an actually existing classical object consisting of actualizably existing quantum components be resolved?
- How can an actualizable object interact with an actual one and still remain in its actualizable state, such as an 'unobserved' electron passing through a double slit?

It is evident, then, that the distinction presented here can only be considered a first step. However, to the extent that any further scientific research in this direction can no longer sidestep an explicit consideration and study of the nature of existence itself, these questions support the general argument of this paper that ontology needs to formally become part of foundational physics.

5 Conclusion

This paper attempted to make a case for ontology to be incorporated explicitly and formally into foundational physics in general, and into the wave function collapse of quantum mechanics in particular. It did so by presenting instances in which ontological considerations weaved into fundamental physics may lead to new ideas and insights. Of these, equation (2), a mathematical representation of the wave function collapse which formally incorporates a purely ontological distinction between two modes of existence, is the instance with the potentially most far-reaching implications.

The distinction introduced here raises several important questions which need to be addressed before it can be considered part of a viable scientific theory that explains what quantum mechanics tells us about reality. This paper did not endeavor to do that here, but an attempt to provide a physical foundation to answer these is presented elsewhere [7][8], and if it is successful, it may well lead to what Kuhn has called a 'paradigm shift'[9].

This paper presented at least one prediction which is in principle empirically falsifiable, but in practice very difficult or perhaps even impossible to test with today's technology. If it is eventually confirmed by experiment, however, then the days in which philosophy may count ontology (or at least that part concerned with what might be intuitively but inexactly called 'physical existence') as an exclusive sub-discipline may be numbered.

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