## Wheeler's self-referential world

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**Abstract**

This paper explores the hypothesis that quantum mechanics (QM) is a description of reality from the perspective of an internal observer—an observer who is simultaneously the subject and object of observation. The idea traces back to the work of J.A. Wheeler [1,2], who argued that the Universe cannot be fully explained from an external standpoint and must be integrated into the process of observation. Without claiming universality, we construct a simple model that demonstrates the emergence of QM within this self-referential framework. The conclusion is that quantum reality is an emergent phenomenon in the worldview of an internal observer.

### 1. Introduction

Quantum mechanics (QM) is an empirical theory. Its foundations remain a subject of debate, and the multitude of interpretations reflects the dissatisfaction of scientists with the current state of affairs, motivating them to continue the search for a deeper theory, as Einstein suggested [3].

The lack of even minimal progress in reductionist approaches to solving the problem of consciousness, on one hand, and the prolonged crisis in understanding the foundations of QM, on the other, hint that the two "hard problems"[1] might be interconnected [4].

Wigner was among the first to realize that the formalism of QM operates not with the external world, but with the states of the observer's consciousness [5]. This implies that consciousness must be formalized and incorporated into physical theory. Such a step is challenging for a physicist, as it represents a move toward subjectivism. A. Linde remarked on this: "It seems that we are dealing with something very, very important, about which we haven't even begun to think" [6].

With the advent of QM, the observer transitioned from being a passive witness to an active participant shaping reality. John Archibald Wheeler, in this regard, suggested replacing the term "observer" with "participant." His well-known statement, "observers are necessary to bring the universe into being," reflects his profound conviction in the fundamental role of the observer in the structure of the universe. Wheeler's student, Hugh Everett III, went even further in understanding the nature of the observer, realizing that there is no collapse, and consequently no

[1] The term "hard problem" were coined by the philosopher David Chalmers in a 1994

contradictions associated with it—there is only the dynamics of quantum states. Later, M.B. Mensky proposed an expanded concept based on Everett's work [7,8], in which he identified selective measurement with consciousness. He considered consciousness a physical property possessed only by living matter. This approach fits within a reductionist narrative but does not address the main question—why and how this property is connected with quantum mechanics.

In the present work, we consider the possibility of a reverse approach. We will demonstrate how quantum mechanics can emerge based on a formalized representation of consciousness.

## Ontology of Quantum Mechanics

We shall outline the fundamental structure and axioms of the model. It is based on a finite set of states of an abstract observer, which we shall formally call states of consciousness. States of consciousness will serve as the fundamental primitives of our construction. This ensures that our model is ultimately background-independent. Indeed, when the observer (their "self") becomes part of a mathematical structure, that very structure—be it a field, group, or space—becomes physical reality for them. Thus, in the framework of this paper, states of consciousness are identified with physical states. For example, the predicative statement (P(x)), meaning "to have the coordinate (x)," describes the corresponding state of consciousness, which takes values from the Boolean set: {0,1}.

Consider a finite set of states of consciousness: $S = \{\psi_1, \psi_2, \dots, \psi_{\mathrm{N}}\}$. The current state of consciousness is always directed at an object (in our case—another state of consciousness). This property of consciousness was termed intentionality by Franz Brentano. Intentional relations form ordered pairs $\{\psi_i, \xi_{\mathrm{j}}\}$, where $\psi_i, \xi_{\mathrm{j}} \in S$. The first element in the parentheses denotes the current state of consciousness. These pairs of states of consciousness will henceforth be referred to as ontological states.

In the spirit of Wheeler's (John Archibald Wheeler) "it from bit" ideology, let us consider an $N^2$-dimensional binary space of ontological states, Ω, with the basis:

$$|\zeta_k\rangle \cong \{\psi_i, \xi_{\mathrm{j}}\};\ \ i, j = 1,2 \dots N,\ k = (i-1) \times n + j. \qquad (2.1)$$

Here, we transition to a consecutive numbering of the basis. More rigorously, we define this as a binary Hamming-normalized space over the field $\mathbb{Z}_2$, with the scalar product defined as $\langle u_k | \mathrm{v}_k \rangle = \sum u_k \mathrm{v}_k$ In such a space, the norm of any vector is numerically equal to the number of non-zero projections: $\|u\|_H = \langle u_k | u_k \rangle$. Since $\|u\|_H \notin \mathbb{Z}_2$, the norm here must be understood narrowly as a function returning the number of non-zero components.

A vector in the ontological space Ω can be represented as a linear combination of the basis vectors:

$$|\Phi\rangle = \sum_1^{N^2} a_k |\zeta_k\rangle \; ; \; a_k \in \mathbb{Z}_2 \qquad (2.3)$$

We assume that the ontological basis is ordered in some fundamental ontological time. If we consider the vector $|\Phi\rangle$ as a set of components corresponding to different moments in time, it essentially describes the evolution of the system in ontological time. Later, we will clarify the physical meaning of ontological time. For now, we note only that ontological time is a measure of the external observer's time, whereas physical time, which we measure with clocks, is a measure of the internal observer's time.

The internal observer's (the subject's) perception of the world is, by definition, limited by his current state of consciousness. Consequently, such an observer does not distinguish between ontological states $\{\psi_i, \xi_{\mathrm{j}}\}$ with the same current state of consciousness $\psi_i$ but different $\xi_{\mathrm{j}}$. This state of affairs will be referred to as physical or subjective incompleteness. The term "subjective" here carries no psychological or philosophical connotation; it simply means that the incompleteness is relative to the internal observer, i.e., the subject. Formally, incompleteness can be expressed by the equivalence relation:

$$\{\psi_i, \xi_{\mathrm{j}}\} \sim \{\psi_i, \xi_k\}, \text{ где } i, j, k = 1,2 \ldots N \qquad (2.4)$$

This equivalence serves as the basis for the factorization of the ontological space $\Omega$ by the criterion of "subjective indistinguishability":

$$Subj \coloneqq {}^{\Omega}/_{\sim} \qquad (2.5)$$

Thus, states of consciousness (which are also physical states) are described by classes of indistinguishable ontological states, which form the equivalence class space with the basis: $|\psi_i\rangle \cong \{\psi_i, \sim\}; \; i = 1,2 \ldots N$

To avoid misunderstanding of the structure considered here, we emphasize that we are factorizing the space $\Omega$ by the basis. Therefore, we have the tensor product $\Omega = \mathrm{Subj} \otimes \mathrm{Obj}$, and accordingly: $\dim(\Omega) = \dim(\mathrm{Subj}) \cdot \dim(\mathrm{Obj})$. Here, $\mathrm{Obj}$ denotes the intentional copy of Subj.

Let $\hat{\hat{P}}_k$ be the projector of the ontological space $\Omega$ onto the subspace of the class $\Phi_k = \{\psi_k, \sim\}$, corresponding to the k-th state of consciousness. It will become clear that the class $\Phi_k$ in quantum mechanics corresponds to the k-th eigenvalue of the observable. Acting with the operator $\hat{\hat{P}}_k$ on an arbitrary vector $|\Phi\rangle$, we obtain the projection vector onto this subspace: $|\Phi_k\rangle = proj_{\Phi_k}(|\Phi\rangle) = \hat{\hat{P}}_k |\Phi\rangle$ This vector lies within the equivalence class subspace $\Phi_k$ and is indistinguishable from other vectors of the same class. However, its norm $\||\Phi_k\rangle\|_H$, equal to the number of non-zero projections, determines the weight of the state $|\psi_k\rangle$ in the factor space of states of consciousness.

The factor space Subj, as defined earlier, does not necessarily "inherit" the structure of the original vector space. Therefore, we extend the field over which the factor space is constructed from the original $\mathbb{Z}_2$ to $\mathbb{Z}_p$, where (p) is prime, and equip this space with a discrete Manhattan metric: $\rho(r, s) = \sum |r_i - s_i|$ where the basis coordinates $r_i, s_i \in \mathbb{Z}_N$. Then, any vector in the factor space can be represented as:

$$|\psi\rangle = \sum \| |\Phi_k\rangle \|_H \cdot |\psi_k\rangle \qquad (2.6)$$

Although strictly speaking we are dealing with a module over the ring $\mathbb{N}$, for simplicity, we will continue to use the term "space." To align our formalism with the formalism of QM, it suffices to rewrite (2.6) in the form:

$$|\psi\rangle = \sum \sqrt{n_k} \cdot |\psi_k\rangle \qquad (2.7)$$

Here, $n_k = \| |\Phi_k\rangle \|_H$ is the number of non-zero projections of the vector $|\Phi_k\rangle$. Since it is impossible to introduce Euclidean metrics on the field $\mathbb{Z}_p$, the coefficients $\sqrt{n_k}$ should not be understood as real numbers in an algebraic sense, but as characteristic functions that return the number of non-zero projections.

It is important to note that both in the QM formalism and in our model, the state space is the space of classes of subjectively indistinguishable (hidden) states. In our case, these hidden states are ontological states, while in QM they are indistinguishable phase states $\psi \sim \psi \cdot e^{i\varphi}$. However, whereas we relate the cardinalities of the classes of ontological states to quantum amplitudes, QM neither explains the origin of amplitudes nor associates any physical meaning with equivalent phase states. Later, we will show that ontological states play the role of quantum-mechanical phases.

The similarity of these mathematical objects suggests that the projective structure of the Hilbert space in QM owes its origin to the physical incompleteness considered here. Indeed, as we have shown, incompleteness inevitably leads to the existence of hidden parameters. In turn, incompleteness imposes fundamental epistemic constraints on the internal observer. Since we equate states of consciousness with physical states, epistemic constraints also become physical and are expressed, in particular, in Heisenberg's uncertainty principle. It is pertinent to recall David Hilton Wolpert's formal argument, stating that it is fundamentally impossible for any intelligence to know everything about the universe of which it is a part [9].

## Ontological Dynamics

Aristotle associated the measure of time with "the change of things" [10]. This reflects a profound understanding that it is not "things" that change within an absolute flow of time, but that time itself is nothing other than the change of "things." We always judge time by observing changes in something; we have no other way to measure time. Following Aristotle, let us assume that any observable change in the states of a system occurs in physical time.

The existence of processes external to consciousness, i.e., fundamentally unobservable processes, is a key distinction between QM and classical mechanics. An example of unobservable dynamics in QM is the stationary state. In a stationary state, the expectation value of an observable $\langle\psi|\hat{x}|\psi\rangle$ does not depend on physical time, whereas the wave function itself oscillates in ontological time (see above). In our model, this situation corresponds to a stationary vector (2.3) in the ontological space $\Omega$.

A stationary vector $|\Phi\rangle \in \Omega$ describes ontological evolution, i.e., the movement of the system in ontological time. Given that ontological states are grouped into equivalence classes $\Phi_k = \{|\psi_\mathrm{k}\rangle \otimes |{\sim}\rangle\}$, the time spent by the system in each of these classes is determined by the number of non-zero projections of the vector $|\Phi\rangle$ onto the subspace $\Phi_k$ of the k-th eigenvalue of the observable. This number defines the coefficients in equation (2.7), which describes the superposition.

In contrast to QM, which assumes the actual simultaneous existence of the components of a superposition, in the model under consideration, simultaneity is interpreted as the inability of the observer to distinguish events that belong to different moments of ontological time but the same moment of physical time.

Different moments of ontological time, while physically indistinguishable, differ in phase. Therefore, any quantum state at any given moment of physical time is degenerate with respect to phase. If a quantum state is a superposition, the result of a measurement (or awareness) will depend on the phase. Thus, phase degeneracy forms the foundation for the Many-Worlds Interpretation (MWI). We will not delve further into this topic here, as it requires separate consideration.

To derive dynamics in physical time, let us rotate the vector $|\Phi\rangle \in \Omega$ in physical time. In general, the evolution of the vector can be written as a recurrence equation:

$$|\Phi_t\rangle = \left[\hat{\mathrm{U}}\right]^{\mathrm{t}} \cdot |\Phi_0\rangle \qquad (3.1)$$

Here, $\hat{\mathrm{U}}$ is a unitary evolution operator acting in the space $\Omega$, and t is discrete physical time. The matrix $\hat{\mathrm{U}}$, from the symmetric group $\mathrm{S_N}$, dimension $N^2 \times N^2$ permutes the basis. This is the most general law of dynamics on a finite field.

Since deterministic evolution on finite spaces is cyclic, i.e., $|\Phi_{t+N}\rangle = |\Phi_t\rangle$ and since our construction is based on finite fields, we can, for convenience, transition to an isomorphic field of roots of unity:

$$|\Phi_\mathrm{t}\rangle = e^{-i\hat{H}\mathrm{t}}|\Phi_0\rangle \qquad (3.2)$$

Here, the vectors $|\Phi\rangle$ are redefined in the basis of the discrete Fourier transform.

The dynamics of quantum states, being supervenient over deterministic ontological dynamics, is not deterministic in the sense mentioned above, as the canonical factor mapping $\widehat{R}: \Omega \longrightarrow S$, which formalizes the reduction (collapse) of a quantum state, is surjective. This leads to an important understanding of the relativity of collapse.

Collapse exists only for the internal observer, whereas objectively (from the perspective of a hypothetical external observer), the system's evolution is deterministic and free of jumps or discontinuities.

From the internal observer's perspective, transitions between observable states appear probabilistic. These probabilities, however, follow deterministic dynamics in exactly the same way as in QM. Besides determinism, there must be ergodicity in the ontological dynamics. Only in this case can the probability be defined as the limit:

$$\mathrm{P} = \lim_{\theta \to \infty} \frac{\theta_\mathrm{i}}{\theta} \qquad (3.3)$$

where $\theta_\mathrm{i}$ is the time, the system spends in the class corresponding to state $|\psi_i\rangle$, and $\theta$ is the current ontological time. With $\Theta_{max} = \mathrm{N}^2$, infinity here is understood conditionally as sufficiently large N.

For the internal observer with a number of states of consciousness (N), the number of ontological states is uncountable, $\mathrm{N}^2 \cong \infty$, so the limit (3.3) becomes strict.

Ergodicity in finite spaces can be justified by the plausible hypothesis of the uniform distribution of a geometric progression over a Galois field [11]. In a sense, this hypothesis is equivalent to the statistical physics postulate of equal probability for all admissible microstates. Based on this assumption, Born's rule in our case is easily derived by simply counting the projections of the evolution vector $|\Phi\rangle$ onto the subspaces of the observables.

## Born's Rule

Let us consider the manifold $\Omega^\times \in \Omega$, formed by vectors $|\Phi\rangle \in \Omega$ with the norm $\langle\Phi|\Phi\rangle = N$, where $N = \dim(Obj)$. Within the framework of axiomatic probability theory, the space $\Omega^\times$ can be viewed as a space of atomic events (elementary outcomes or simple events) [12]. The set of projections $proj_{\Phi_i}(|\Phi\rangle)$ of the vector $|\Phi\rangle$ onto subspaces of the corresponding observables constitutes an event. Each event satisfies the normalization condition:

$$\sum_1^N \left\| proj_{\Phi_i}(|\Phi\rangle) \right\|^2 = N \qquad (4.1)$$

It is important to note that the term "event" here corresponds to the concept of nonselective measurement. This refers to a situation where the result of a measurement is not consciously recognized and, therefore, can only be described by a probability distribution. The set of all possible events forms a σ -algebra of events £. The event space is defined as the triplet:

$$\mathcal{H} = (\Omega^{\times}, £, P) \qquad (4.2)$$

where (P) is the normalized probabilistic measure, defined as follows:

$$P(x_i) = \frac{1}{N}\langle\Phi|\hat{\hat{P}}_i|\Phi\rangle = \frac{1}{N}\langle\Phi| \begin{pmatrix} 0 & & & & & & & & \\ & \ddots & & & & & & & \\ & & 0 & & & & & & \\ & & & 1 & & & & & \\ & & & & \ddots & & & & \\ & & & & & 1 & & & \\ & & & & & & 0 & & \\ & & & & & & & \ddots & \\ & & & & & & & & 0 \end{pmatrix} |\Phi\rangle = \frac{1}{N}\langle\Phi_i|\Phi_i\rangle = \frac{n_i}{N} \qquad (4.3)$$

Here, $P_i$ is the probability of selective measurement corresponding to the class $\{\Phi\}_i$. $\hat{\hat{P}}_i$ - is the ontological projection operator associated with the eigenvalue of the observable, as introduced earlier. For clarity, the projector is represented in matrix form. In QM, for non-degenerate states, the diagonal of the projector contains only one unit. In our case, the number of units in group (i) is determined by the dimensionality of the subspace of the equivalence class.

Authors of various QM interpretations are often concerned with the so-called preferred basis problem. The question is posed as follows: why, during measurement, does the quantum system "choose" one definite state instead of remaining in a superposition of multiple states? Or, in other words, why does our world appear classical?

In the context of our model, which is focused on exploring the foundations of QM rather than its interpretation, this question loses its meaning. The choice is not made by the system but by the observer, who is constrained by a finite set of states of consciousness. What the observer observes is what they declare as the basis. In other words, the basis does not exist a priori; it is assigned by the observer. Discussions about superposition in this regard take on a counterfactual nature.

## Conclusions

In recent times, increasing efforts have been made to integrate the observer into the fabric of physical theory. It is worth noting the similarity between the approach discussed here and Rovelli's relational interpretation (RQM) [14], which rejects the concept of an absolute independent observer. It also bears resemblance to works [15, 16] that are structurally close to our approach, where the authors ad hoc introduce the idea of indistinguishability of "microstates" by a conscious agent (observer), and from this derive Born's rule. Similarly, David Hoffman employs reverse reductionism to derive quantum mechanics from consciousness [17].

In this work, we have shown how quantum mechanics can emerge based on a formalized representation of consciousness. In our model, the observer is an abstract subject observing itself. In form, this is reminiscent of J.A. Wheeler's

"Participatory Universe" [2]. However, the emphasis here is on self-reference, which, in the case of finite systems, analogously to Gödel's incompleteness theorems, generates "physical incompleteness." As a result, the world for the internal observer acquires non-classical properties, which are described by quantum mechanics.

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