An Information-Based Solution to the Measurement Problem in Quantum Mechanics

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One of the most intriguing challenges that physics has been confronting during the recent decades is the measurement problem in quantum mechanics (QM). Despite the extensive research on this enigmatic phenomenon, science is still searching an explanation for the irreversible transformation of a measured system from a wave-like (quantum) state to a deterministic state. To confront this challenge, we propose the "*Vivo-Information*" (VI) framework, aimed at providing a complete model of the QM measurement process by formalizing the hitherto fuzzy role of the observer. The model provides a resolution to the QM measurement problem by defining and integrating the observer, expressed in information terms, into the measurement process. The suggested framework does not require amendments to the laws of physics, but rather provides an information-driven explanation to the above problem.

I. INTRODUCTION

One of the most intriguing challenges that physics has been confronting during the recent decades is the measurement problem in quantum mechanics (QM). While QM measurements have been conducted and recorded regularly, science is still searching an explanation for the irreversible transformation of a measured system from a wave-like (quantum) probabilistic state to a post-measurement, deterministic state.

According to Neumann [1], one of the most profound obstacles in solving the above problem is that the measurement process cannot be explained by the current rules of physics, since the change that occurs in the system as a result of measurement cannot be described by a set of physical forces enacted on the measured system.

Several solutions have been proposed during the past decades (see Section II), e.g., the "guiding wave" theory Bohm [2], the spontaneous localization theory Ghirardi et al. [3], and an observer-dependent theory Rovelli [4]. While each such theory solves several aspects of the QM measurement problem, none provides a complete solution to this conundrum Hájíček [5]. More specifically, none of the theories explains completely the collapse mechanism of the wave function and the "selection" of a specific result. In addition, despite the central part of the observer in the measurement process, there is no formal definition of its *role* and *nature* Bell [6]. For example, it is not clear whether the wave-function collapse require the involvement of a conscious observer, or can it occur even when the observer is, for example, a measurement instrument? Finally, there is still no framework for understanding the physics and consequences of a *delayed* measurement choice that according to experiments also causes a wave-function collapse, and by that, allegedly influences the particle's/system's state in the past.

To confront this challenge, we propose the "*Vivo-Information*" (VI) theory, aimed at providing a complete solution to the measurement problem in QM by formalizing the hitherto fuzzy role of the observer. To do that we first analyze the properties of the observer from an information based viewpoint in QM. Then, we integrate the representation of the observer in information terms within the measurement process. Consequently, we show how this integration solves the measurement problem in QM and by that connects between quantum mechanics and the observed reality. Finally, we also suggest several experiment conducts to support the proposed theory.

The newly suggested theory provides a solution to all of the open issues that arise from state-of-the-art interpretations, and at the same time endows with the collection of all their strengths, under one unified framework. VI is the only theory among previously suggested solutions that: (a) defines what measurement is; (b) formalizes the nature of the experimenter; (c) provides a model for the wave function collapse mechanism; (d) provides a model for the delayed measurement process; and (e) explains the meaning of wave-functions in the description of particles and systems prior to measurement. The suggested framework does not require amendments to the laws of physics, but rather provides an observer-driven explanation to the above conundrum.

The rest of the paper is organized as follows: we present related work in Section II, positioning our work with respect to previous research. In Section **??** we present and analyze the properties of the observer in terms of information, based on (a) the information coordination properties in quantum mechanics; and (b) an evolution-based viewpoint. Then, in Section III B we show how the suggested theory provides a complete solution to the measurement problem

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and its related phenomena. To empirically examine the VI theory we suggest experiment frameworks in Section IV. We conclude in Section V.

II. BACKGROUND: LITERATURE SURVEY

Several theories were suggested during the past century aiming to provide a solution to the measurement problem in QM. Wigner, for example, maintains that the human consciousness is responsible for the wave function collapse Wigner [7]. Nevertheless, this theory lacks a formal description of consciousness and how it actually affects wave functions.

In order to avoid the need for explaining the "collapse" process, some theories eliminate it from quantum mechanics. The "guiding wave" theory describes every quantum particle as a combination of a guiding wave and a hidden variable, which is the well-defined location of the particle Bohm [2]. According to this description, the wave-function guides the particle's motion and evolves in time according to the Schrödinger equation without any collapse, and the particle possesses a well-defined location at all times, which is revealed by measurement. The wave-function in this theory has a double role: on one hand it serves as a force field operating on the particle (and by that guiding its motion), and on the other hand it determines the statistical distribution of the locations of different particles that are defined by similar wave-functions. This theory can explain the particle-wave duality phenomenon. Nevertheless, it has the following weaknesses: (a) it handles location observables differently than the way it handles all other observables; (b) the force field has no physical basis and it is difficult to justify the relationship between the wave function and the statistical distribution of the location coordinates; (c) there are difficulties in applying the theory on single particles such as an electron or a hydrogen atom Lazarou [8]; (d) when the system consists of more than one particle, the force field operates in an abstract mathematical space with three dimensions for each particle (and not in the real physical space in which the particles move).

The above group of solutions also includes the "relative-state" theory Everett III [9] that explains the wave function collapse as a subjective experience caused by the observer's multiple consciousness states. According to this theory, following each experiment, the observer himself is also in a superposition of states: each relates to a different possible outcome of the experiment. Although this theory is able to explain the wave function collapse phenomenon, few criticisms were pointed at this theory, including: (a) the preferred basis problem: why is the world we experience in practice compatible to the wave function decomposition according to a specific basis in Hilbert Space? (meaning, why each of the observer's consciousness states is always coupled to single basic states and never to one of their optional superpositions?); (b) the meaning of the probability of different measurement outcomes is unclear; (c) the addition of multiple universes in order to solve this single problem is inconsistent with the Occam's Razor principle; (d) the theory cannot be tested. The "many worlds" interpretation to this theory suggests that there is an enormous or even an infinity of parallel universes, in which all possible scenarios - that can and did not occur in our universe - take place DeWitt [10], Wheeler [11], Zurek [12]. Nevertheless, the independent existence of each superposition element only deepens the preferred basis problem. Zeh Zeh [13] presents a different version to this theory, by replacing the multiple worlds with multiple brains for each observer in a single universe. Although this theory supports a single universe, it possesses the same weaknesses of the relative-state theory.

Another group of theories eliminates the measurement act itself from quantum mechanics and describes what we experience during measurement as a routine process in the quantum reality, which is not an outcome of the measurement act alone. The "quantum decoherence" theory suggests that the interaction between a quantum system and its environment is responsible for shifting from the quantum world of superpositions to the classic macroscopic world. Although this theory provides an explanation to why the observer observes a single state as a result of measurement, it does not provide an explanation for the measurement paradox Adler [14], Zeh [15], since all wave-function components still exist within a global superposition. Therefore, this theory is close to the many-worlds theory Zeh [16], Zurek [17]. Since the many-worlds theory can be derived solely from the quantum mechanics equations Everett III [9], DeWitt [10], it is difficult to justify the additional definitions and interpretations that this theory suggests.

The "spontaneous wave-function collapse" theory Ghirardi et al. [3] suggests that occasionally and randomly, particles undergo a spontaneous process of localization ("hitting"), in which their wave-function collapses. After the localization process, if the particle was entangled with other particles, then the entire system's wave-function also collapses accordingly. Since measurement, according to this theory, entails quantum entanglement, a quantum collapse occurs whenever subatomic particles are measured. This is because the measured particle becomes entangled with the very large number of particles that make up the measuring device. The theory's main virtue is in providing an explanation to the measurement problem as a simple outcome of basic dynamics of particles. Nevertheless, it does not define what "entanglement" is. Does entanglement take place only when the measurement involves a human observer? This open issue brings us back to the problem of defining the measurement act. Moreover, observers in different reference systems may determine a different set of entangled particles due to measurement. This situation can create a paradox in which a "localized" particle that influences a system's state according to one observer, may not be part of this system according to another observer and therefore cannot affect those particles. Finally, it is not clear why the localization process does not occur during other physical processes on the macroscopic level that do not involve an observer.

The "relational quantum mechanics interpretation" Rovelli [4] claims that the state of a quantum system is observer-dependent, that is, the state is the relation between the observer and the system. According to this interpretation any system can be referred to as an "observer," whether it includes an element of consciousness or not, and measurement is in fact a regular physical interaction that does not involve a real wave-function collapse. The theory's strength is that it does not differentiate between the quantum and the classic worlds. Nevertheless, its weakness is that it does not define clearly which events are considered "interactions" or "measurements."

In summary, the different theories, as described above, confront the measurement problem from various viewpoints, but while each solves several aspects, other problems emerge, and therefore none provides a complete solution to this conundrum. While some theories try to eliminate the measurement act and the observer from their solution, none accomplishes to avoid these elements. Therefore, any complete theory should clearly define two central notions: (a) what a measurement (or a measurement-like) action is; and (b) what the nature of the observer is: does measurement requires the involvement of a conscious person, or can it also occur when the observer is, for example, a cat, or even a measurement instrument?

In addition, none of the theories presents a solution to the following issues: (a) explaining the mechanism for selecting one of the wave-function's states due to measurement; (b) explaining the meaning of the superposition of states prior to measurement; (c) explaining the source of the preferred basis for decomposing state vectors according to single basic states; and (d) providing an explanation for the delayed decision phenomenon. A further more detailed analysis of the shortcomings of state-of-the-art theories can be found in Hájíček [5], Genovese [18].

III. A SOLUTION TO THE MEASUREMENT PROBLEM IN QM

The suggested solution, *Vivo Information* (VI) theory, utilizes *life* in terms of *information* as an essential component in completing the missing links of the measurement process. To explain the solution, we will first define the properties of life in terms of information, from an evolution-based viewpoint. Then, we will integrate the information based definition within the QM measurement process, and show a complete model to the measurement process.

A. Life in a Quantum-Based Universe

The description of particles (and systems) that are represented simultaneously by ***various*** basic states of the same observable (wave function) is a physical description that is not new and which has many supports in the field of quantum mechanics. That said, we, the living creatures, experience a reality by which each observable of any particle or system is represented by a ***single*** basic state. For example, when watching a tennis ball, it seems to always be in one place (for example, on our racquet, at the moment it is hit) and we never see it in two or more places (for example, ***also*** on the opponent's racquet simultaneously). Therefore, the question is posed: why do we experience such a "single-state" reality?

One simple answer can be: because this reality reflects the macroscopic world. And indeed, the classical theories in physics perceive the macroscopic world as a single-state world as regards to the observables that describe it and distinguish it from the microscopic multiple-state world. This differentiation between the two worlds is carried out based solely on the level of ***granularity***, with no principled explanation why this difference exists and without a definite boundary (e.g. a numerical size) between the two worlds.

This understanding shifts the question presented above towards the question: what is the difference between the microscopic world and the macroscopic world? Since the same world is being discussed, which is examined through various "magnifying glasses," we claim that the size-based explanation is not valid. Additionally, measurements on the quantum level also discover a single state for a particle or a quantum system, so that also at this granular level there are single states for various observables. Therefore, we deduce that when single states of observables are being considered, there is no fundamental physical difference between these two worlds of granularity and that the only cause for a single state per observable arises solely from ***our*** observation. Therefore, we do not differentiate between the microscopic and macroscopic worlds according to the order of magnitude they represent, but between a world that is ***unknown*** to us and a world that contains particles and systems that were ***entered into our information system*** (our brains).

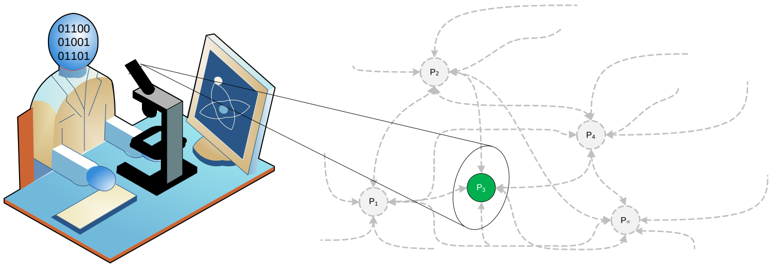

Figure 1: An ability of living entities to *stabilize* their environment is an essential characteristic for the existence of life.

By understanding that ***our*** observation is related to the single-state representation of particles and systems we return to the question: why do ***we*** experience the world in this way? If it is not related to the "world," we will try to find the answer within ***ourselves*** while rephrasing the question in the following manner: why do ***we, living entities***, have the trait that causes ***us*** to have this particular experience of the world? When we come to examine "ourselves" we shall base ourselves on the Darwinist notion according to which each of our common traits, as living creatures, has an evolutionary justification Darwin [19], and we will try to answer the question: why do the life forms that developed on the Earth (at least, the human ones) have the trait of a *single-state experience* of the reality regarding the various observables that compose it?

In order to answer this question, we shall first define what life is. According to Allaby [20], life is "a state of physical entities that utilize substances derived from outside themselves for the purposes of growth, the repair of their own structure, and the maintenance of their functional systems, and that also reproduce…" Based upon the evolution principle, it can be expected that a ***single-state-based environment*** (an environment in which observables are described by a single basic state) is an essential condition for the existence of life (in its current form), and that the more the environment is based on single states for observables, thus it will be possible to better support the characteristics of life. And indeed, this trait is essential for the existence of life, since it enables the usage of *information* for survival, growth and reproduction purposes. For example, it is better to eat an apple that has 100% probability of being ready than an apple in a "fuzzy" state, having 50% probability of being ready and 50% probability of being sour; or it is easier to escape a lion that is 100% behind us than a lion that may be 40% behind us or 60% in front of our escape route.

At this point one can claim that single states are not necessarily required for the existence of life if our mind is able to react to multiple simultaneous states of the same observable in different ways simultaneously (also as a wave function). This is possible, but it leads us to multi-brains or multi-worlds theories in which each scenario refers to a single basic state, and this brings us back to the same conclusion of a *single-state-based environment* for a living entity.

To further illustrate the necessity of a single-state-based environment for the existence of life more examples are presented as follows: (1) the more that "substances derived from outside themselves" are located in a more specific spatial location, so it will be possible to "utilize" them in a better and definite way; (2) the process of cell building that is required for growth and also the process that passes on the biologic information required for reproduction have a far better chance in succeeding, the more the cellular information is based on single values and does not change over the course of the process; (3) the single-state "perspective" can also aid living beings in reacting to environmental situations more efficiently (e.g. identifying dangers and finding definite and unequivocal avoidance actions, or identifying water sources and investing in growing roots in their direction).

1. *Mechanisms for Environmental Stability*

The quantum world, by definition, can be described by a collection of wave functions of particles and systems[24]. Nevertheless, a single-state-based environment is essential for the existence of life. Therefore, the question is posed: which mechanisms can cause living entities to experience single basic states for observables? (see illustration in Fig. 1). Without such a mechanism life will not exist in the form we know.

To answer the above question we present two possible mechanisms for living entities to "stabilize" their environment (meaning: determining single basic states for observables) within the quantum world: one – is the *objective mechanism*, which includes an actual influence of a living entity on the information of particles, and the second – the *subjective mechanism*, which includes a change in the knowledge of a living entity regarding particles in its environment, as detailed below. Note that the subjective mechanism modifies only the leaving entity's knowledge, and does not imply any actual change on the quantum world. At this point, it is important to note that when referring to information possessed by a living entity we use the term *knowledge*, which is defined as "the fact or condition of having information or of being learned" [25].

The objective mechanism. According to the objective mechanism, a living body is capable of increasing the weight of a specific basic state within a particle's (or a system's) wave function and by that weakening or even canceling the remaining optional basic states. This information modification is carried out through the measurement of a particle's state using interfaces to the universe platform (in the case of humans: our five senses), where this process of measurement and the fixation of single basic states is carried out according to the following principles. We, living entities, are limited to the observation of a single basic state for each measured observable (a trait, that as has been said, created the possibility of the existence of life and which became more advanced over the course of evolution as a survival means). Therefore, as a result of the measurement act, living entities identify one basic state among the possible states in the wave function and insert this state into their database using their information system. Consequently, as the knowledge of the living entities is part of the quantum world, information is added to the quantum world regarding the particle's selected basic state and thus the measured particle's wave function collapses into a single basic state. Let us note: the database and its management system (the information system) of living entities is the mechanism that absorbs information in a way that allows them to react according to it. In complex living beings this means the brain and its memory, and in simpler living beings this means the cellular mechanism that absorbs environmental information (for example: temperature) and thus enables it to respond according to it. For convenience, we shall call this mechanism a "brain" for all forms of life.

The subjective mechanism. According to the subjective mechanism, every living entity is "aware" of one feasible scenario of the universe platform (that is, a set of chosen basic states – one for each measured observable). Life is a kind of an information register (even if in its most primitive form only the latest scenario is being regarded), and when we, living entities, measure the state of a particle, we are in fact attaching one option from among its possible basic states to the entire feasible scenario that is preserved in our brains regarding the universe, without changing the physical state of the universe wave function (the absolute reality). In fact, this mechanism resembles the objective mechanism, where the difference is in the influence of the addition of information to our information reservoir. While according to the objective mechanism there is an actual influence on the quantum world (or the universe platform), according to this mechanism the quantum world remains as is, and only the information in our information system changes. At this point it is worthy to note that in spite of the use of consciousness terms such as: "aware" or "subjective" – both above mentioned mechanisms do not require the awareness of the living entity, and the usage of such terms is carried out solely for illustrative description needs. The subjective mechanism raises the question: how does the synchronicity hold between the reality scenarios we living entities each have? One explanation can be that each living entity is cognizant of a scenario in which the entire environment agrees to the measurement results of which it is aware.

It is important to note that the process of knowledge stabilization is not based upon new elements in physics. On the contrary, this process is based on the usage of information, and indeed the entire universe's platform is founded on information at the most basic level, as the factor that determines its configuration and its evolvement in time. Therefore, the moment that mechanisms were created that make use of (or even manipulate) this information (AKA: the living beings) and the most developed among them are also aware of (and remember) the results of that usage (for example, humans) – it is no wonder that the universe which is depicted in their consciousness behaves in this fashion.

Another topic that is worthy of mention is the ability of living entities to notice a single basic state for each measured observable. Two cerebral mechanisms can support this: (a) our brains are capable of noticing only single states of this type; (b) our brains choose states of this type. This trait is the one that creates a preferred basis for decomposing vectors in the Hilbert Space (that is, decomposition of state vectors as a superposition of basic states), but it should be recalled that this preferred basis emerges from the mechanism of life, and not out of the basic physics laws of nature.

Out of all this emerges that the whole stable environment we find around us is the result of measurements and observations that we have conducted during our lifetimes – no matter which of the environment stabilization mechanisms is applied, and that other living entities carried out during their lifetimes – if the objective mechanism is applied. This environment includes specific, stable and basic states only for observables of particles and systems that were observed, while other particles and systems surrounding us, as we reveal in experiments at the quantum level, can still possess simultaneously a number of basic states for each of their observables. In other words, the reality experienced by living entities contains a partial and single-state picture out of the universe platform, a kind of projection of a discrete scenario, which enables us, the living beings, to survive as separate and consistent entities within this platform.

Before proceeding, it is important to note that the ability of stabilizing an environment belongs to *all* living entities, whether it is human, amoeba or plant, and thus the theory does not distinguish between intelligent and less-intelligent entities. The emphasis is on the addition of stative knowledge by the living entity as a factor that influences the state

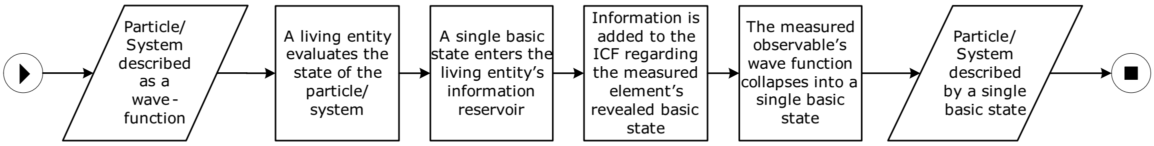

Figure 2: An illustration of the measurement process, as defined by the VI theory.

of particles and systems, and therefore there is no need even for the consciousness of the living entity. The moment of knowledge creation in the living entity is the moment from which it can make any use of that knowledge.

B. Explaining the Measurement Process in QM

The VI theory, as presented in Section III A, establishes the position of the information factor in the universe platform and takes into account the meaning of life in such a universe as a perspective for understanding the phenotypes discovered in it. In doing so, the VI theory provides a solution for the measurement problem in quantum mechanics and enables comprehension of QM related phenomena from a complete and consistent viewpoint.

The VI theory defines the act of measurement as a process in which a living entity of any type evaluates the state of a particle or a system through interfaces that it has to the universe platform (for example: the sense of smell). Living entities are able to observe only a single basic state for each measured observable and thus, as a result of a measurement act, a single basic state enters the living entity's information reservoir that contains the measurement result. Consequently, information is added to the quantum world regarding the measured element's revealed basic state and thus, the wave function of the measured observable collapses into that single basic state – whether through an actual change in the quantum world or through a change in the living entity's knowledge (when applying the objective mechanism or the subjective mechanism, respectively). The moment of knowledge creation in the living entity is the moment from which it can use that knowledge in any fashion. This process is illustrated in Fig. 2, based on the YAWL van der Aalst and Ter Hofstede [21] process modeling conventions, using parallelograms for representing states/data.

The VI theory also provides a framework for understanding the outcomes of a delayed measurement choice in the following manner: the moment that we decide to add knowledge (to carry out a measurement) to the universe of which we are conscious, this datum is added to our description of the universe, even if the datum is related to a time from the past. The revealed basic state from the past is a state that suits the scenario that we are experiencing, and therefore it is integrated without contradictions with the states that we are aware of in the present time and in other past times. According to the subjective mechanism for stabilizing an environment on the quantum world, no real physical change occurs in the universe platform as a result of this delayed decision, and thus there is no contradiction with past scenarios in this case. The objective mechanism also provides a complete and adequate framework for understanding this phenomenon: the moment of the decision to carry out a measurement, the probability of a specific single state of the wave function indeed strengthens at a point of time in the past and other scenarios that developed from this past moment and until the moment of measurement are canceled. However, from our point of view, after this point in time (in the past) we are aware only of consistent states of the same revealed state in our perceived universe, so that in fact from our point of view there is no fundamental difference between a regular measurement and a delayed decision measurement, even when applying the objective mechanism. The difference between the objective mechanism and the subjective mechanism in this case is that the first includes a physical cancellation of scenarios that are not compliant with the set of scenarios that initiate with the revealed past state and that evolved from that point in past time and up until the time of the measurement decision. The cancellation of those scenarios in past time cannot create a logical contradiction both for living entities – as they are aware only of the history of the revealed state – and in the universe platform – since there is no contradiction in the flow of states that occurred there.

The VI theory advances state-of-the-art works in the following way: it presents an interpretation for the measurement problem that overcomes all open issues and drawbacks of state-of-the-art interpretations and at the same time endows with the collection of all their different strengths - within a single conceptual framework. VI is the only theory of the measurement problem that: (a) defines what measurement is; (b) defines the nature of the experimenter (a living entity); (c) defines the mechanism for the collapse of wave functions at the time of measurement; and (d) provides an explanation for the outcomes of a delayed observation decision.

Additionally, the suggested interpretation recognizes the wave function as a real physical element (since information is a physical element) and it does not require the definition of hidden variables. In addition, the interpretation includes a single universe, and particles exist in a well-defined manner also before measurement. Finally, the interpretation refers equally to the observable of location and to other observables, and also, as the interpretation deals with elementary particles, there is no problem of applying it to isolated systems or to very small assemblies.

The interpretation is also compatible with Bell's inequality principle according to which at least one of the classic traits of *objectivity* and *locality* must be violated by any successful physical theory that refers to quantum phenomena Mermin [22]. Objectivity means that the theory is capable of providing a description of a physical reality that exists in the same way even when it is not observed Ben-Dov [23]. According to the objective mechanism for environment stabilization on the quantum world, the physical reality changes as a result of observations, and thus, allegedly, the objectivity trait is violated. In spite of this, it should be noted that particles, according to this mechanism, truly and clearly exist in reality also before measurement is conducted. On the other hand, according to the subjective mechanism, observations influence the living entities' subjective perception of the universe, but this perception does not modify the absolute reality, which is to say: the physical state of the universe platform. Therefore, the objectivity trait is preserved if the subjective mechanism is applied as the basis for stabilizing the environment of living entities.

Locality means that everything is found in its place and that there is no remote direct influence of one body on another body Ben-Dov [23]. Therefore, even if the VI theory sustains the objectivity trait (if we support the subjective mechanism), this theory is non-local, as it allows (and even is based on) remote influence between particles (as has been said, their state is being updated in an immediate manner in accordance to the state of the remainder of particles in the universe). Nevertheless, it must be noted that the nature of the non-locality trait in the VI theory is *passive*, meaning: particles do not influence other particles in a mechanical or intentional way, but: the state of any particle changes independently in accordance to the state of other particles in-order to maintain its feasibility (a passive trait that emerges from the most profound definition of a particle). At this point we will also note that although non-locality violates the spirit of relativity, the VI theory is still consistent with the special theory of relativity, since it does not include faster-than-light *transmissions* of information.

C. Explanations to Additional Universe Phenotypes

Based on the VI theory it is possible to explain related phenomena and attributes of the measurement act as follows.

- **Bridging the gap between the macroscopic and microscopic worlds.** The above definition of the measurement process provides an explanation for the difference between the world as reflected from quantum mechanics and the experienced reality: while in the first one particles and systems can be represented by a superposition of multiple basic states, the second one contains a single basic state for each measured observable. From a more general viewpoint, the theory bridges the gap between the macroscopic world described mainly through the general theory of relativity and the microscopic world described mainly through quantum mechanics based on the understanding that there is *no* fundamental physical difference between these two worlds of granularity. The only differentiating factor between the deterministic and random worlds that are reflected in them – emerges solely from our observation. That is to say, the VI theory distinguishes between a world that is *unknown* to us (living entities) and a world that contains particles and systems that are *known* to our information system. Henceforth we shall call those two worlds: the *measured* world and the *non-measured* world.

- **Explaining the reason for the "preferred basis" phenomenon.** The above definition of the measurement process also explains why the preferred basis for state vector decomposition after measurement is according to single basic states although each superposition of basic states also represents a possible state prior to the measurement act. As explained, the preferred basis emerges from the mechanism of life, and not out of the basic physics laws of nature.

- **Explaining the meaning of randomness in QM.** Based upon the VI theory, it is possible also to explain the meaning of randomness in the physical world, as follows. After delving into the meaning of life on the universe platform, it is possible to interpret the multiple states of each particle's observable and the probability related to them also in a *subjective* manner. According to this approach, the universe platform is composed of "*joker*" particles - particles that are fundamentally identical, for whom each of their observables is represented simultaneously by all of its possible states at an equal probability (or, alternatively, equivalently: "naked" particles to whom it is possible to attribute any state according to necessity). Based on such "joker" particles, the particle's wave function, and more specifically, the probabilistic combination of states, actually reflects the extent of belonging of each basic state to the scenario to which we are aware. For example, probabilities of the location of a particle we are currently measuring will be significantly higher for places in the space of the room in which we are and closer to zero on the other side of the universe. We should notice that these probabilities are close but do not equal zero, and that is because within the scenario we are aware of there are also very small probabilities for unusual states, like: our immediate passage through a worm-hole to the other side of the universe.

IV. SUGGESTED EXPERIMENTS

In this section we present three experiment directions aimed at enabling an empirical examination of the VI theory. A detailed design of these experiments is not within the scope of this paper.

The first experiment is aimed at examining whether an act of measurement that does not include an addition of knowledge to a living entity causes a wave function collapse of the measured system. One of the ways to do that is examining whether the wave function of a given system collapses in case the experimenter does not know *what* is being measured. If the wave function in this case does not collapse, the experiment will show that only the addition of knowledge causes the collapse and not the act of measurement per se. In this case it will be possible to conclude that the interaction between the system and the instrument of measurement does not cause the wave-function collapse, as suggested by some state-of-the-art theories (e.g. the spontaneous wave-function collapse theory Ghirardi et al. [3]). Such an experiment can be tricky, because it requires the determination whether the wave function collapsed without adding knowledge to the experimenter, and thus it is required to plan it precisely.

An example of a framework for conducting such an experiment is presented as follows. According to this example, experimenter A plans a system that can measure three selected observables of a particle (for example: location, energy and spin). The measurement mechanism is set-up in a way that the range of measurement results of each of the observables is similar (for example, when measuring each of the observables the measurement mechanism always outputs the measurement result as a number within the range of [0,1]). When experimenter A pushes a button, one of the observables is randomly chosen for measurement and the result is presented on a screen. Experimenter B, who does not know anything about the system that is being measured, looks at the screen and sees the presented result[26]. In this experiment we expect that the particle's wave function will *not* collapse. One must make certain that no one can ever discover which observable was chosen for measurement (the uncertainty should be built into the system), for example, even if someone on another planet observes the light beams that arrived from the same experiment – she would not be able to find out which observable was chosen.

The second experiment is aimed to test whether quantum entanglement between particles occurs in cases where the experimenter does not know whether the initial conditions that entangle these particles occurred. Similarly to the first experiment, this experiment also examines the effect of knowledge on the quantum state of particles and systems, but this time it is based on a different phenomenon (quantum entanglement).

Finally, the third experiment is aimed at showing that changes of particle/system wave-functions are not independent events, but are dependent on and coordinated with the quantum state (wave-functions) of other particles and systems.

V. CONCLUSION

In this work we have presented a solution to the measurement problem in quantum mechanics and showed that this solution provides an answer to all open issues in state-of-the-art interpretations and at the same time endows with the collection of all their different strengths. We consider this work as a starting point for understanding phenomena in quantum mechanics and for understanding the role and meaning of life in such reality, yet several research issues remain open, including: (a) performing experiments to support the proposed theory (as suggested in Section IV); and (b) discovering additional phenomena and processes in physics that can be supported by the VI theory.

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[24] For convenience, from now on, when mentioning particles in the context of the quantum world we also refer to systems.
[25] http://www.merriam-webster.com/dictionary/knowledge
[26] It would be possible to carry out the experiment only with experimenter A. Experimenter B was added to the experiment in order to further separate between the editor of the experiment and the knowledgeable observer and by that to further reduce the observer's knowledge of the experiment.