Instant Interpretation of Quantum Mechanics

Huy Khanh Hoang

E-mail: hoang.huy.khanh@gmail.com

We suggest a new interpretation of Quantum Mechanics, in which the system state vectors are identified with q-instants — new elements of reality that are similar to time instants but can be overlapped with each other. We show that this new interpretation provides a simple and objective solution to the measurement problem, while preserving the general validity of the Schrodinger equation as well as the superposition principle in Quantum Mechanics.

1 Introduction

In spite of the extraordinary practical successes of Quantum Mechanics, the foundations of the theory contain unresolved problems, of which the most commonly cited is the measurement problem. In standard Quantum Mechanics, the quantum state evolves according to the Schrodinger equation into a linear superposition of different states, but the actual measurements always find the physical system in a single state, with some probability given by Quantum Mechanics. To bridge this gap between theory and observed reality, different interpretations of Quantum Mechanics have been suggested, ranging from the conventional Copenhagen interpretation to Hidden-variables and Many-worlds interpretations.

The Copenhagen interpretation of Quantum Mechanics proposed a process of *collapse* which is responsible for the reduction of the superposition into a single state. This postulate of wavefunction collapse was widely regarded as artificial, ad-hoc and does not represent a satisfactory solution to the measurement problem. Hidden-variable theories are proposed as alternative interpretations in which the behavior of measurement could be understood by the assumptions on the existence of inaccessible local variables with definite values which determine the measurement outcome. However, Bell's celebrated inequality [1], and the more recent GHZ argument [2], show that a Hidden-variable theory which is consistent with Quantum Mechanics would have to be non-local and therefore contradictory to Relativity. The best known of such theory is Bohmian mechanics [3, 4], to which many physicists feel that it looks contrived. It was deliberately designed to give predictions which are in all details identical to conventional Quantum Mechanics.

In Everett's *Relative State* formulation [5], also known as the Many-worlds interpretation [6], one insists on the general validity of the superposition principle. The final state after the measurement is considered to be the full superposition state, and the measurement process is interpreted as the splitting of the system + apparatus into various branches (these are often called Everett branches) only one of which we observe. All measurement outcomes in the superposition thus coexist as separate real world outcomes. This means that, in some sense, there is a very large, perhaps infinite, number of universes. Most physicists find this extremely unattractive. Moreover, in this interpretation it is not clear how to recover the empirical quantum mechanical probabilities.

In this paper we suggest a new interpretation of Quantum Mechanics, called Instant interpretation, which can give a simple, objective solution to the measurement problem and does not have the difficulties mentioned above. It assumes, as in the Everett interpretations, the general validity of the Schrodinger equation as well as the superposition principle of Quantum Mechanics. Basically, it consists in the introduction of the concept of *q-instant* (or *quantum instant*), and the interpretation of the system state vectors as the q-instants at which the quantum system is present or occurred. The q-instant, being a new concept of instant, is an element of reality that has the same role as time instants in classical physics: quantum events take place at different q-instants similarly to that classical events take place at different time instants. However, q-instants have new properties, especially the superposition, that are fundamentally different to time instants. Mathematically, q-instants are vector-like instants, while time instants are point-like instants. The difference in behavior of quantum and classical objects is essentially due to such differences between q-instants and time instants.

A particularly intriguing consequence of the linear time evolution of the quantum system in the context of Instant interpretation is that it leads, in quantum observation, to the *apparent* collapse phenomenon, or the *apparent unique measurement outcome*, an illusion that happens to any conscious-being observer. This is the key point to resolve the measurement problem by the Instant interpretation.

The outline of the article is as follows. We start with a preliminary introduction of the concept of quantum instant in Quantum Mechanics. In Section 3, we present the Instant interpretation and the formalism of Quantum Mechanics in this interpretation, named as *Instant Quantum Mechanics*. In Section 4, we show how the new interpretation can provide a simple and objective solution to the problem of definite outcome in quantum measurement theory, i.e. the problem related to the fact that a particular experiment on a quantum system always gives a unique result. Finally, in Section 5, we give some conclusion remarks on the instant formalism of Quantum Mechanics and the role of quantum decoherence in this new interpretation.

2 Preliminary Concept of Quantum Instant

Before introducing the concept of q-instants in Quantum Mechanics, we shall describe briefly the basic meaning and property of its closed concept — the time instant notion.

From the physical viewpoint, time is part of the fundamental structure of the universe, a dimension in which events occur. A time instant or time point in this dimension is thus considered as a *holder* for the presence of events and objects. Each of the object's presences is called an occurrence of the object. A physical object at two different instants is considered as the same object, and not as two objects. Similarly, the worlds at different instants in the past, present and future are different occurrences of a single world, not of multiple worlds. We consider this as the basic meaning of the instant notion.

One particular property of time instant is its *distinctness*: Different time instants are strictly distinguished in the sense that when a physical object is being present in a given time instant, it is not present in other time instants. In other words, due to this separateness, the object completely leaves one time instant, before it can occur in another time instant.

The notion of q-instants that we use to interpret the wave function state in Quantum Mechanics has the same basic meaning as time instants, that is, q-instants are new *holders* for the presences of a physical system.

We shall illustrate the introduction of this new concept of instant in Quantum Mechanics by means of a simple example. Let ψ be a state vector such that

$$\psi = \frac{1}{\sqrt{2}}\left(\psi_1 + \psi_2\right), \tag{1}$$

where ψ_1 and ψ_2 are two orthogonal state vectors (correspond to two eigenstates of some observable F).

What it really means a physical system in such a superposed state ψ? It seems likely that the system is half in the state ψ_1 and half in ψ_2, a property of quantum objects that is usually considered as weird and inexplicable (as it is typically expressed for the behavior of the particle in the two-slit experiment).

Using the concept of instants, however, we can explain the superposition in (1) as describing the occurrences of the system at two different *instants*: one associated with the state vector ψ_1 and other with ψ_2.

Note that we do not intend to add some hidden-time τ associated with the system states by some mapping $f(\tau_i) = \psi_i$. Instead of introducing such classical extra hidden-variables that control the occurrences of the state ψ_i, we identify the state ψ_i with the *instant* itself. We then try to know what are the properties of this new kind of instant, which we call *quantum instant* or *q-instant*.

In fact, by considering the state vectors ψ, ψ_1 and ψ_2 in the superposition (1) as q-instants, we see that the q-instant concept exhibits intriguing new properties, compared with conventional time instants: different q-instants can be superposed or overlapped, in contrast with the distinctness property mentioned above of time instants.

In our example, the q-instant ψ is a superposition of two q-instants ψ_1 and ψ_2, it overlaps with each of these two q-instants. On the contrary, the two q-instants ψ_1 and ψ_2 are orthogonal, they are distinct and do not overlap with each other as in the case of two different time instants. The overlap of two q-instants has the consequence that when an object is being present in one instant, one of its occurrences can be found in another instant.

Mathematically, q-instants are vector-like instants, while time instants are point-like instants. In fact, due to its superposition property, quantum instant has the structure of a vector and is not represented by a point on the real line R like a time instant. The inner product of two vectors can then be used to measure the overlap of the two corresponding q-instants.

3 Formalism of Quantum Mechanics in Instant Interpretation

In the above section, we have illustrated the introduction of the notion of q-instant in Quantum Mechanics. For the sake of simplicity, we have identified the state vector of a physical object with the q-instant at which the object located. Taking into account the time dimension, we see that the state vector of a physical object evolves in time, while the q-instants are rather something independent with time. Indeed, in the Instant interpretation, we will consider that, for each physical system, besides the time dimension, there exists independently a continuum of q-instants in which the system takes its presences. Quantum events take place in time dimension as well as in the q-instant continuum. The state vector, in the Instant interpretation, is then considered as the *representation* of a q-instant at a time t. So the q-instant itself is independent with time, but its representation, i.e. the state vector, evolves in time according to the Schrodinger equation. Note that, in this sense, the q-instant corresponds to the state vector in the Heisenberg representation of Quantum Mechanics.

The axioms of Quantum Mechanics in the Instant interpretation are as follows:

- *A1* Every physical system S is associated to a Hilbert space H_S and a q-instant continuum $\mathbb{Q}_S$ in which the system takes its presences.
- *A2* Each q-instant Q of the continuum $\mathbb{Q}_S$ is described, at each time t, by a normalized vector $|\psi\rangle$ of H_S. The time evolution of the q-instant representation, i.e. the

vector $|\psi\rangle$ representing the instant Q, is governed by the Schrodinger equation:

$$i\hbar\,\frac{\partial\,|\psi(t)\rangle}{\partial t} = H\,|\psi(t)\rangle\ . \tag{2}$$

The operator H is the Hamiltonian of the system S.

A3 Let Q_1, Q_2 be two q-instants of the continuum $\mathbb{Q}_S$ represented, at some given time, respectively by two vectors ψ_1, ψ_2 of H_S, then $|\langle\psi_1|\psi_2\rangle|^2$ is the measure of presence of q-instant Q_1 in q-instant Q_2.

A4 Each physical observable O of the system S is represented by a self-adjoined operator in H_S. If a q-instant Q of the system S is described, at some time t, by an eigenvector $|O_n\rangle$ of an observable O then the value of the observable O of the system S at q-instant Q and time t is o_n, where o_n is the corresponding eigen-value of $|O_n\rangle$.

Quantum Mechanics based on these axioms is called *Instant Quantum Mechanics*. In the following, we will give some remarks about its axioms and the underlying concept q-instants. In particular, we will show how the notion of probability can be defined in the context of the Instant interpretation.

(R1) For each q-instant Q, we denote by $Q(t)$ the vector $|\psi\rangle$ of H_S that describes it at time t. We say that the system S at time t and q-instant Q is in the *state* ψ. Let U be the time unitary evolution of the system, then:

- at time t_0 and q-instant Q, the system is in the state $Q(t_0) \equiv |\psi_0\rangle$, and
- at time t and q-instant Q, the system is in the state $Q(t) \equiv |\psi\rangle = U(t)\,|\psi_0\rangle$.

Thus, according to Instant Quantum Mechanics, the state of a physical system is determined by a time instant and a q-instant. This is in contrast with standard Quantum Mechanics in which only the time t determines the *state* ψ of a physical system. In standard Quantum Mechanics, one basic axiom is that the physical system at each time t is described by a state vector ψ. This axiom seems evident, and the practical successes of Quantum Mechanics confirm it. However, as we shall show in the next sections, this is just apparently true, and the description of *state* in Instant Quantum Mechanics is not in contradiction with practical observations. While in standard Quantum Mechanics, to fix an initial system setting, we use the expression "*Suppose at time* t_0*, the system* S *is in the state* ψ", in the Instant interpretation, we can equivalently express this by "*Consider the system* S *at time* t_0 *and q-instant* Q *such that* $Q(t_0) = \psi$".

(R2) Similar to the state space, the q-instant continuum $\mathbb{Q}_S$ has also the structure of a Hilbert vector space. This structure is defined as follows.

Let, at some given time t, $|\psi\rangle$, $|\psi_1\rangle$ and $|\psi_2\rangle$ be the state vectors that describe respectively the q-instants Q, Q_1 and Q_2. Then, we define:

- $Q = c_1Q_1 + c_2Q_2$ if $|\psi\rangle = c_1\,|\psi_1\rangle + c_2\,|\psi_2\rangle$,
- the inner product $\langle Q_1|Q_2\rangle = \langle\psi_1|\psi_2\rangle$.

Due to the linearity and unitarity of the time evolution of the q-instants representation, it is easy to see that the above definitions are consistent, that is, they are time-independent.

Let $|\psi\rangle = \sum_{i=1}^n c_i\,|\psi_i\rangle$ and Q, Q_i, $1 \leqslant i \leqslant n$, be q-instants such that $Q(t) = |\psi\rangle$, $Q_i(t) = |\psi_i\rangle$, then we have the following facts:

- q-instant Q is a superposition of the q-instants Q_i: $Q = \sum_{i=1}^n c_iQ_i$,
- at time t and q-instant Q_i, the state of the system is $|\psi_i\rangle$, for $1 \leqslant i \leqslant n$,
- at time t and q-instant Q, the state of the system is $|\psi\rangle$.

(R3) Since q-instants are vectors, there is no order relation between them as in the case of time instants. There is thus no concept of *next* q-instant of a q-instant. If the system is being present at instant Q, it makes no sense to ask *what q-instant it will be present next*? Instead, there is a superposition between the different instants of the q-instant continuum. Between any two q-instants Q_α and Q_β there is a *weight* $w_{\alpha\beta} = |\langle Q_\alpha|Q_\beta\rangle|^2$, which is the *measure of presence or overlap* of the instant Q_α in the instant Q_β, defined in the axiom *A3*. If Q_α and Q_β are overlapped, i.e. $w_{\alpha\beta} \neq 0$, then when the system is present in instant Q_α, it is present also in Q_β. If $w_{\alpha\beta} = 0$, we say that the two instants Q_α and Q_β are *orthogonal*, that is, when the system is present in one instant, it is not present in the other instant.

(R4) The notion of *current instant*, having a straightforward meaning in the case of time instants, is not directly defined for the case of q-instants. It is not globally defined for the whole q-instant continuum and it makes no sense to ask *which is the current q-instant of the q-instant continuum ?* In fact, in its usual sense, the *current* instant means the instant that the system is being present at and not elsewhere. This has sense only if the so-called current instant is orthogonal with all the others, a requirement which is impossible if we consider the whole q-instant continuum. The notion of *current q-instant* is thus defined *only* with respect to a *context* in which this orthogonality requirement is satisfied. We define it as follows: A context is a pair (Q, E), where Q is a q-instant and $E = \{Q_i\}$ is an orthogonal basis. Suppose that $Q = \sum_i c_iQ_i$ is the expansion of Q in this basis. So when the system is present at instant Q, it will present also at all instants Q_i with $c_i \neq 0$. But as the instants Q_i's of the basis E are pairwise orthogonal, there is always only one instant Q_i of E that the system is *currently* present, this Q_i is called the *current q-instant* of the context (Q, E). As the system will present in all the above instants Q_i's, all these instants will become the current q-instant while the system under consideration is in the context (Q, E). The role of the current instant is thus alternatively played by each of the q-instants of E. This notion of current q-instant is therefore similar to that

of current time instant for the time dimension. However, different to the case of time instants, in which all time instants equally take the role of current instant during the flow of time, the assignment of this role in the case of q-instants is proportional to the measure of presence of each q-instant Q_i in the context q-instant Q. The measure of presence $|\langle Q|Q_i\rangle|^2$ determines therefore the *probability* that the q-instant Q_i becomes the current instant of (Q, E). One can understand the intuition behind this probability notion by means of the following thought experiment: Imagine a person who lives in the q-instant dimension E, in which he takes a long sleep and then wakes up at some q-instant of E. Suppose that before sleeping the person does not know at which instant he will wake up. He knows it only when he wakes up and opens his eyes, at that moment he realizes that he is currently at some instant Q_i. So, before opening his eyes, the person can only predict with a certain probability which instant Q_i he is currently at. This probability for an instant Q_i is the *probability* that Q_i becomes the current instant, and it is proportional to the measure of presence of Q_i.

4 The measurement process and the apparent collapse phenomenon

In this section, we recall briefly first the standard description of the measurement process within traditional Quantum Mechanics and the problem arising from it, usually referred as *the measurement problem* in the literature. We then show how our Instant interpretation of Quantum Mechanics can give a simple and objective solution to this problem.

4.1 Measurements in traditional Quantum Mechanics — the problem of definite outcome

A standard scheme using pure Quantum Mechanics to describe the measurement process is the one devised by von Neumann (1932). In this schema, both the measured system and the apparatus are considered as quantum objects.

Let H_S be the Hilbert space of the measured system S and $\{|e_i\rangle\}$ be the eigenvectors of the operator F representing the observable to be measured. Let H_A be the Hilbert space of the apparatus A and $\{|a_i\rangle\}$ be the basis vectors of H_A, where the $|a_i\rangle$'s are assumed to correspond to macroscopically distinguishable *pointer* positions that correspond to the outcome of a measurement if S is in the state $|e_i\rangle$. The apparatus A is in the initial *ready* state $|a_0\rangle$.

The total system $S \otimes A$, assumed to be represented by the Hilbert product space $H_{SA} = H_S \otimes H_A$, evolves according to the Schrodinger equation. Let U be the time evolution of the total system from the initial state to the final state of the measuring process.

Suppose that the measured system S is initially in one of the eigenvector state $|e_i\rangle$ then $U(|e_i\rangle|a_0\rangle) = |e_i\rangle|a_i\rangle$ where $|\phi_f\rangle = |e_i\rangle|a_i\rangle$ is the final state of the total system + apparatus $S \otimes A$. The outcome $|a_i\rangle$ of the apparatus A can be predicted with certainty merely from the unitary dynamics.

Now, consider the case of measurement in which the system S is initially prepared not in the eigenstate $|e_i\rangle$ but in a superposition of the form $\sum_i c_i|e_i\rangle$. Due to the linearity of the Schrodinger equation, the final state $|\phi_f\rangle$ of total system is:

$$|\phi_f\rangle = U(\sum_i c_i|e_i\rangle|a_0\rangle) = \sum_i c_i|e_i\rangle|a_i\rangle\ . \tag{3}$$

So the final state $|\phi_f\rangle$ describes a state that does not correspond to a definite state of the apparatus. This is in contrast to what is actually perceived at the end of the measurement: in actual measurements, the observer always finds the apparatus in a definite pointer state $|a_i\rangle$, for some i, but not in a superposition of these states. The difficulty to understand this fact is typically referred to as the measurement problem in the literature.

Von Neumann's approach (like all other standard presentations of Quantum Mechanics) assumes that after the first stage of the measurement process, described as above, a second non-linear, indeterministic process takes place, the *reduction* (or *collapse*) of the wave packet, that involves $S \otimes A$ *jumping* from the entangled state $\sum_i c_i|e_i\rangle|a_i\rangle$ into the state $|e_i\rangle|a_i\rangle$ for some i. It's obvious that the wave-packet reduction postulate, abandoning the general validity of the Schrodinger equation without specifying any physical conditions under which the linear evolution fails, is *ad hoc* and does not consequently represent a satisfactory solution to the measurement problem.

In the last few decades, some important advances related to a theoretical understanding of the collapse process have been made. This new theoretical framework, called quantum decoherence, supersedes previous notions of instantaneous collapse and provides an explanation for the absence of quantum coherence after measurement [7–11]. While this theory correctly predicts the form and probability distribution of the final eigenstates, it does not explain the observation of a unique stable pointer state at the end of a measurement [12, 13].

4.2 Solution from Instant Quantum Mechanics

We will show how the Instant interpretation based on the concept of q-instants allows a simple and objective solution to the measurement problem. The above description of the measurement process can be reformulated in Instant Quantum Mechanics as follows:

According to the Instant interpretation, the combined system $S \otimes A$ takes its presences in a continuum $\mathbb{Q}_{SA}$ of q-instants, each of which is represented at each time t by a normalized vector of the Hilbert product space $H_{SA} = H_S \otimes H_A$.

Following the remark *(R1)* of Section 3, the initial setting (according to standard Quantum Mechanics) in which the combined system $S \otimes A$ is in the state

$$|\phi_0\rangle = \sum_i c_i \, |e_i\rangle \, |a_0\rangle \; . \qquad (4)$$

is equivalent to the initial setting (according to the Instant interpretation) in which the combined system $S \otimes A$ under consideration is being present at the q-instant Q of the continuum $\mathbb{Q}_{SA}$ such that

$$Q(t_0) = |\phi_0\rangle \; , \qquad (5)$$

where $|\phi_0\rangle$ is defined in (4).

For each i, let Q_i be the q-instant of $S \otimes A$ such that

$$Q_i(t_0) = |\phi_i\rangle = |e_i\rangle \, |a_0\rangle \; . \qquad (6)$$

The instants Q_i's are, hence, orthogonal one with another. Following the remark *(R2)* of Section 3, the instant Q is spanned over this set of instants as follows:

$$Q = \sum_i c_i \, Q_i \; . \qquad (7)$$

Following the axiom *A3*, the $|c_i|^2$ is the measure of presence of the system $S \otimes A$ in instant Q_i as long as the system is being present in instant Q.

The state vectors, representing the instants Q and Q_i's, evolve independently in time following the Schrodinger equation. At the end of the measurement process, we have:

$$Q_i(t_f) = |e_i\rangle \, |a_i\rangle \; , \qquad (8)$$

$$Q(t_f) = \sum_i c_i \, |e_i\rangle \, |a_i\rangle \; . \qquad (9)$$

From (8), (9) we see that after measurement:

- at time t_f and q-instant Q, the state of the combined system is $\sum_i c_i \, |e_i\rangle \, |a_i\rangle$;
- at time t_f and q-instant Q_i, the state of the combined system is $|e_i\rangle \, |a_i\rangle$, hence the state of the apparatus is $|a_i\rangle$.

Thus, after measurement, the observer sees different outcomes $|a_i\rangle$'s, at different instants Q_i's. So far, the description still seems to be in contrast to what is actually perceived by the observer at the end of the measurement, i.e. to the following fact:

Fact 1. *The observer always sees the apparatus in one definite state $|a_i\rangle$, for some i, after the measurement.*

The difficulty to explain Fact 1 is usually referred as *the problem of definite outcome* in quantum measurement theory. However, we will show that Fact 1 is intriguingly not true, it is an illusion of the observer. More precisely, we will show, according to the Instant interpretation, the following *apparent "collapse"* phenomenon (or the phenomenon of *apparent unique measurement outcome*):

Fact 2. *The observer does see different measurement outcomes, but it seems to him that there is only one unique measurement outcome and the apparatus is in one definite state $|a_i\rangle$, for some i, after the measurement.*

Proof. To prove this fact we will take into account the presence of the observer in the measurement process by considering him as a component of the total system. We will see that the illusion in Fact 2 comes from the property of time evolution independence of different q-instants in the measurement process and its impacts on the observer's recognition of the world.

To be consistent and objective, we will treat the observer quantum mechanically, that is, as a quantum object. We can simply write $|O_i\rangle$ to denote the state of the observer seeing the apparatus in position $|a_i\rangle$. However, to well understand the illusion, we need to consider the cognitive aspect of the observer in a little more detail. A conscious being can observe the world and use his brain cells to stock information he perceived. What make he feels that he is seeing an event, is the result of a process of recognition during which the brain cells "memorize" the event.

Let C be the set of memory cells that the observer uses in the recognition of the apparatus state, and C_i be the content of C when the observer perceives that the apparatus state is $|a_i\rangle$. This content C_i is considered as the *proof* that the observer perceives the apparatus in position $|a_i\rangle$.

Suppose that at some instant the content of the cells is C_i and the observer actually perceives that the apparatus state is $|a_i\rangle$. If the cells contents are later destroyed, not only the observer will not see the apparatus being in the state $|a_i\rangle$, but as his concerned memory data is lost, he will feel that he has never seen the apparatus being in the state $|a_i\rangle$. If, alternatively, the cell contents are changed and replaced by C_j, not only the observer will see that the apparatus is now in the state $|a_j\rangle$, but as his old data is lost, for him the apparatus have never been in the state $|a_i\rangle$.

This is what happens to the observer in the measurement process according to Instant Quantum Mechanics.

In fact, including the observer in the measurement process, the Hilbert space of the total system will be the product $H_S \otimes H_A \otimes H_O$, where H_O is the Hilbert space of the observer. We assume that H_O is spanned over the basis of state vectors $\{|O_i, C_i\rangle\}$ where the $|O_i, C_i\rangle$ describes the state of the observer seeing the apparatus in position $|a_i\rangle$ and having his memory cells contents C_i.

Initially, the total system $S \otimes A \otimes O$ under consideration is being present at the q-instant Q of the continuum $\mathbb{Q}_{SAO}$ such that

$$Q(t_0) = |\phi_0\rangle = \sum_i c_i \, |e_i\rangle \, |a_0\rangle \, |O_0, C_0\rangle \; . \qquad (10)$$

The total system containing the measured system, the apparatus and the observer with his memory cells evolves in time following the Schrodinger equation during the measurement process.

At the end of measurement, at time t_f, similar to (8), (9), we have:

$$Q_i(t_f) = |e_i\rangle\,|a_i\rangle\,|O_i, C_i\rangle\ , \tag{11}$$

$$Q(t_f) = \sum c_i\,|e_i\rangle\,|a_i\rangle\,|O_i, C_i\rangle\ . \tag{12}$$

So, after the measurement process, similar to the apparatus and the observer, the cells C takes its presences in different q-instants, and at q-instant Q_i, the observer memory cells content is C_i. Note that, due to the time evolution independence of the cells contents in different q-instants, the content of the cells C in one q-instant is not influenced by its contents in other q-instants.

We consider the impact of this on the observer behavior. After measurement, at instant Q_i, the cells content is C_i, but at another instant Q_j, the cells content is replaced by C_j. So at instant Q_j, the observer loses all information of his memory cells at instant Q_i. Due to the time evolution independence of the cells contents at Q_i and Q_j, basing on his memory cells information at Q_j, the observer has no trace or proof that he has ever lived in instant Q_i. By consequence, at instant Q_j, the observer sees the apparatus in position $|a_j\rangle$, but he absolutely *forgets* that he has ever lived in q-instant Q_i and seen the apparatus in position $|a_i\rangle$. In other words, after each measurement, the observer does see different outcomes at different q-instants, but he believes that there is only one outcome, the one that he is currently seeing. □

So we have proved Fact 2 and solve therefore the problem of definite outcome. How about the probability of an outcome? Objectively, all outcomes are present after the measurement, so the probability of an outcome $|a_i\rangle$ here must be understood as the probability that an outcome $|a_i\rangle$ becomes the one that is *currently* perceived (and illusorily considered as unique) by the observer. In other words, the probability of an outcome $|a_i\rangle$ is the probability that the corresponding instant Q_i is the *current q-instant* in which the observer presents. As we have remarked in *R4* of Section 3, this notion of *current q-instant* is defined with respect to a context. In our case, corresponding to the setting of the measurement process, this context is (Q, E), where Q is the q-instant under consideration of the total system at time t_0, and $E = \{Q_i\}$ is the set of orthogonal instants Q_i in which the measured observable F has a definite value. So from *R4* of Section 3, we see that the probability of the outcome $|a_i\rangle$ is the measure of presence of the instant Q_i in instant Q which, from (7), is equal to $|c_i|^2$.

5 Concluding remarks

1. We note that the phenomenon of apparent unique outcome in the measurement process (Fact 2 of Section 4.2) illustrates also a remark about the definition of *state* in the Instant interpretation in *R1* of Section 3: the state of a physical system is dependent not only on time but also on q-instant. In fact, as we have seen in Section 4.2, the *state* of the total system at the end of measurement is dependent on the q-instants at which the system presents. But, as demonstrated there, the observer is unconscious about this, for him the *state* of a quantum object is always unique at any time instant. The description of state in the Instant interpretation is thus not in contradiction with practical observations.

2. In the Instant interpretation, we consider that, like microscopic objects, a macroscopic object, e.g. an apparatus, also takes its presences in a q-instant continuum which supports the superposition principle. If Q_1 and Q_2 are two q-instants in which the object can present, then it can also present in a q-instant which is a superposition of Q_1 and Q_2. The question is why can we observe a macroscopic object such as an apparatus in q-instants in which its pointer position is either *up* or *down*, but never in a q-instant in which its pointer is in a superposition of these positions.

This is the problem of *classicality* of macroscopic objects, to which decoherence theory, in particular the environment-induced decoherence, can provide an explanation. In fact, recent development in this domain [7–9, 11, 14–16] has shown that there exists, for macroscopic objects, certain *preferred sets of states*, often referred to as *pointer states* that are robust. These states are determined by the form of the interaction between the system and its environment and are suggested to correspond to the *classical* states of our experience. Thus, for a macroscopic object, one can not observe all of its Hilbert state vector space but only a small subset of it. In the context of Instant interpretation, this means that, while a macroscopic object can present in all q-instants of the continuum, we can observe it only in q-instants that are described by these robust classical states.

In summary, with respect to the measurement problem in Quantum Mechanics, decoherence theory can provide an explanation to the *classicality appearance* of the measurement outcomes, while the Instant interpretation allows to explain the observation of *an unique outcome* at the end of a measurement.

Submitted on July 28, 2008 / Accepted on August 07, 2008

References

1. Bell J. S. On the Einstein-Podolsky-Rosen paradox. *Physics*, 1964, v. 1, 195–200.
2. Greenberger D. M., Horne M. A., Zeilinger A. Going Beyond Bell's Theorem. *Bell's Theorem, Quantum Theory and Conceptions of the Universe*. M. Kafatos (Ed.), Kluwer Academic, 1989, 69–72.
3. Bohm D. A Suggested Interpretation of the Quantum Theory in Terms of "Hidden Variables" I. *Phys. Rev.*, 1952, v. 85, 166–179.

4. Bohm D. A Suggested Interpretation of the Quantum Theory in Terms of "Hidden Variables" II. *Phys. Rev.*, 1952, v. 85, 180–193.
5. Everett H. "Relative State" Formulation of Quantum Mechanics. *Rev. Mod. Phys.*, 1957, v. 29, 454–462.
6. DeWitt B. S., Graham N. The Many-Worlds Interpretation of Quantum Mechanics. Princeton Univ. Press, 1973.
7. Zurek W. H. Pointer basis of quantum apparatus: Into what mixture does the wave packet collapse? *Phys. Rev. D*, 1981, v. 24, 1516–1525.
8. Zurek W. H. Environment-induced superselection rules. *Phys. Rev. D*, 1982, v. 26, 1862–1880.
9. Zurek, W. H. Decoherence and the Transition from Quantum to Classical. *Phys. Today*, 1991, v. 44, 36-44.
10. Wheeler J. A., Zurek W. H. Quantum Theory and Measurement. Princeton University Press, Princeton, NJ, 1983.
11. Joos E., Zeh H. D. The emergence of classical properties through interaction with the environment. *Zeitschrift für Physik B*, 1985, v. 59, 223–243.
12. Adler S. L. Why decoherence has not solved the measurement problem: a response to P.W. Anderson. arXiv: quant-ph/0112095.
13. Bub J. Interpreting the Quantum World. Cambridge University Press, 1997.
14. Zurek, W. H. Decoherence, einselection and the quantum origins of the classical, *Rev. Mod. Phys.*, 2003, v. 75, 715–775. arXiv: quant-phy/0105127.
15. Joos E., Zeh H. D., Kiefer C., Giulini D., Kupsch J., Stamatescu I. -O. Decoherence and the appearance of a classical world in quantum theory. Springer, 2003.
16. Schlosshauer M. Decoherence, the measurement problem and interpretations of quantum mechanics. *Rev. Mod. Phys.*, 2004, v. 76, 1267–1305. arXiv: quant-ph/0312059.