Dynamics and Thickness of Time

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Abstract

This paper shows how different quantum phenomena such as superposition and entanglement can be easily explained by a three-dimensional structure of time which also explains some cosmological features such as the observed flatness and isotropy of the Universe.

Key words: entanglement, uncertainty, inflation, flatness.

1. Introduction

Time is used to label moments in the universe and to measure duration elapsed between events [1]. However, according to relativity, the labeling of events is not equivalent to the measuring of the elapsed time between these different events and moreover, time is combined with space to form a single block of spacetime.

On the other hand, in conventional quantum physics, time is not an observable and is usually considered as a scalar quantity used to parametrize a quantum system. It is even proposed by some papers that time has no real existence and is simply an emergent property derived from quantum correlations. In particular, the quantization of general relativity yields the Wheeler-De Witt equation [2, 3] predicting a Universe without time.

In this paper, it is simply intended to model time in a way that makes sense of certain phenomena of nature such as superposition, measurement and entanglement [4] in quantum physics as well as the flatness and horizon problems in cosmology.

According to the Copenhagen interpretation [5], measurement prompts a wave function initially in a superposition state to be reduced into a single state of what came to be known as collapse of the wave function [6]. But according to the many-world interpretation [7, 8], there is no wave function collapse and all measurement results exist but in different worlds.

Another feature of quantum mechanics is entanglement which occurs when the constituents of a system cannot be described independently. Such phenomena were the subject of many papers and in particular, a paper by Einstein et al [9] describing what came to be known as the EPR paradox in which entanglement is considered to violate locality. However, Bell [10] proved that the principle of locality, was inconsistent with the predictions of quantum theory. Moreover, entanglement was verified experimentally by measuring the polarization or spin of entangled particles in different directions and the results were in agreement with quantum mechanics [11, 12].

In this paper, time is considered to have a certain "thickness" that gives an alternative and more logical interpretation of the above quantum phenomena.

Concerning cosmology, the standard big bang theory explains the expansion of the Universe, the spectrum of the cosmic microwave background radiation as well as plenty other observations. However, it leaves some questions unanswered and seems to demand very carefully chosen initial conditions [13]. Indeed, the current observational situation seems to indicate that the Universe is far more spatially flat, isotropic and homogeneous on large scales, than can be explained by an initial explosion. In particular, the observations of the cosmic background radiation show that the temperature of the early Universe was extremely uniform. This feature, known as the horizon problem cannot be accounted for by the standard big bang theory. Another special feature, known as the flatness problem requires from the big bang to specify the mass density of the early Universe with extreme precision [14]. These initial conditions were explained by Guth [15] by an inflation phenomenon at the early stage of the Universe. This inflationary scenario provides a dynamical mechanism that explains the evolution of the early Universe towards flatness, homogeneity and isotropy.

Here again, the proposed time-thickness model is used to give an alternative scenario that explains these seemingly special initial conditions of the Universe but leads to a reassessment of the actual standard model of evolution.

2. Time-lines

In this section, it is proposed to describe time as evolving dynamically in a three-dimensional vector space. It can be defined in a reference frame consisting of a three-dimensional coordinate system (for example a Cartesian coordinate system). The first coordinate axis is named "physical-time-axis" or $t - axis$, the second coordinate axis is named "the uncertainty-time-axis" or $\eta - axis$ and finally, the third coordinate axis is named "the state-time-axis" or $\theta - axis$. The physical-time-axis is the usual time-axis with respect to which are defined the symmetric fundamental laws of nature, the other ones will be described in the next sections.

To each quantum system is associated a time-trajectory-like-line, hereinafter referred to as, "elementary-time-line" formed by a succession of ordered points of intrinsic dynamical elementary-time instants specified by the triplets $t_e = (t, \eta, \theta\ )$.

The elementary-time-lines of all quantum systems are regarded to be elementary constituents of a universal or global-time-tube. An element of the global-time-tube can be defined by the following metric:

$$dt_G{}^2 = dt^2 + d\eta^{\ 2} + d\theta^{\ 2} \qquad (1)$$

The projection of different elementary-time-lines onto the $t - axis$ generates a relative physical-time order between these time-lines. This order gives the illusion that all quantum systems are governed by an external time and that each physical-time-coordinate forms an event.

In the next sections, the different features of the elementary-time-lines will be considered. In particular, section 3 will be devoted to the quantum features of the elementary-time-lines whereas, section 4 will be dedicated to the cosmic features of the global-time-tube.

3. Quantum features of a dynamical time-line

A quantum system (e.g. spin of a particle) can be defined by a state-vector in an orthonormal eigenvector basis. In particular, for any observable A, (when no observation is done yet), the state-vector $|\psi\rangle$ of a quantum system is initially defined by a superposition of vector projections in an eigenbasis $\{|\psi_i\rangle\}$. In other words, the state-vector $|\psi\rangle$ is initially defined as a linear combination of the different possible sub-states. The normalized state-vector of the quantum system can thus be expressed as follows:

$$|\psi\rangle = \sum_i c_i \, |\psi_i\rangle \quad (2)$$

where $|\psi_i\rangle$ are the sub-states of the quantum system defined by $\langle\psi_i|\psi_j\rangle = \delta_{ij}$ (Kronecker delta) and the coefficients c_i (or wave function) of the state-vector $|\psi\rangle$ define the probability amplitudes in the specific orthonormal eigenvector basis $\{|\psi_i\rangle\}$. Thus, each state-vector $|\psi\rangle$ is modeled as a superposition of sub-states.

According to the present model, the evolution of the state-vector $|\psi\rangle$ is defined at each elementary-time instant specified by the triplet $t_e = (t, \eta, \theta\ )$. The projection of the state-vector $|\psi\rangle$ onto the $t - axis$ evolves according to the Schrödinger equation, whereas, the projection of the state-vector $|\psi\rangle$ onto the $\theta - axis$ evolves according to an "internal" transition mechanism from one sub-state to another and the projection of the state-vector $|\psi\rangle$ onto the $\eta - axis$ evolves according to another "internal" transition mechanism from one eigenbase (or chain of sub-states) to another. Thus, the elementary-time-line corresponding to the state-vector $|\psi\rangle$ can be represented as being composed of a plurality of elementary components, hereafter called "elementary-time-filaments", each one being associated with a corresponding sub-state. Each elementary-time-filament evolves along the physical time according to the Schrödinger equation whereas, transitions or jumps from one elementary-time-filament into another are governed by internal mechanisms.

On the other hand, the elementary-time-line can be represented at each physical-time index by a two-dimensional slice in the plane (η, θ). The transition mechanism along the $\theta - axis$ is autonomous from that along the $\eta - axis$ and thus, each mechanism can be studied independently from the other.

In the following sections, the projection of the state-vector $|\psi\rangle$ onto the different time-axis will be studied separately.

3.1. Evolution along the physical-time-axis

Conventionally, the state-vector $|\psi\rangle$ evolves according to the deterministic law of Schrödinger equation when projected onto the $t - axis$. In particular, each sub-state evolves along its elementary-time-filament whose projection onto the physical-time-axis is governed by the Schrödinger equation.

3.2. Evolution along the state-time-axis

At each current physical-time instant t, a state-vector is expressed in function of a set of amplitudes of probability that clearly define the probability distribution of the different sub-states composing the state-vector. Thus, the "internal" mechanism of transitions of the different sub-states along the $\theta - axis$ can be modeled by either a periodic process or a stationary Markovian process. In either case, the state space is defined by a set of eigenvectors $\{|\lambda_i(\theta)\rangle\}$, wherein, each sub-state $|\lambda_i(\theta)\rangle$ indicates the state of the state-vector at a corresponding state-index θ. The process can be fully represented by a state-diagram defining the transitions between the different sub-states as well as their corresponding life-times, hereafter called “holding state-times”.

When the “internal” transition mechanism is considered to be periodic, the state-time-index may then be defined in a domain limited to an interval $\Delta\theta = [\theta_a \;\; \theta_b]$ wherein, for simplicity reasons, $\Delta\theta$ is considered to be dimensionless and normalized (i.e. $\Delta\theta = 1$). On the other hand, it is straightforward to suppose that each sub-state can only jump into a single other sub-state and two different sub-states cannot jump into the same sub-state. In other words, the state-diagram of the periodic process forms a one-to-one correspondence between the set of sub-states into itself (i.e. a simple permutation). This process can thus be completely described by defining the permutation correspondence between the different sub-states and by assigning a “holding state-time” $\Delta\theta_j$ to each sub-state. The “holding state-time” $\Delta\theta_j$ represents the “state-life-time” of the corresponding sub-state $|\lambda_j\rangle$ and depends on the corresponding coefficient c_j of the state-vector $|\lambda\rangle$. Indeed, the outcome probability of each sub-state depends on its life-state-time and as the state-time-period $\Delta\theta$ (i.e. the sum of all “holding state-times”) is chosen to be equal to one, then each holding state-time $\Delta\theta_j$ represents the outcome probability of the corresponding sub-state $|\lambda_j\rangle$.

On the other hand, if the “internal” transition mechanism is governed by a stationary Markovian process, the state-time-index may also be defined in a domain limited to an interval $\Delta\theta = [\theta_a \;\; \theta_b]$, wherein $\Delta\theta$ denotes the state-time-term needed for the stationary Markov chain to reach a steady-state solution. The process is considered to be a homogeneous Continuous-Time Markov Chain (CTMC) whose state space is formed by a set of eigenvectors $\{|\lambda_i(\theta)\rangle\}$, where the sub-state $|\lambda_i(\theta)\rangle$ indicates the state of the state-vector at the corresponding state-time-index θ. The rate of transition or “jump” from a sub-state $|\lambda_i(\theta)\rangle$ into another sub-state $|\lambda_j(\theta)\rangle$ is noted q_{ij} and the transitions between the different sub-states can be described by a transition (or generator) matrix $Q = (q_{ij})$. The holding state-time (i.e., the state-time spent in the sub-state $|\lambda_i(\theta)\rangle$ before jumping into the subsequent sub-state) is noted $h_i(\theta)$ and is exponentially distributed in function of a holding time rate $v_i(\theta)$ which corresponds to the transition rate out of the sub-state $|\lambda_i(\theta)\rangle$. Thus, the “holding state-time” can be expressed as: $h_i(\theta) \sim e^{v_i(\theta)}$. The transition probability from a sub-state $|\lambda_i(\theta)\rangle$ into another sub-state $|\lambda_j(\theta)\rangle$ is noted p_{ij} where $p_{ij} = q_{ij} / v_i$ and where the transition probabilities between the different sub-states can be described by a transition probability matrix $P = (p_{ij})$.

The probability for the state-vector to be in the sub-state $|\lambda_i(\theta)\rangle$ at state-time-index θ is denoted by $\pi_i(\theta) = P(|\psi(\theta)\rangle = |\lambda_i(\theta)\rangle)$ and the state-probability vector is defined by the n-tuple of probabilities of all the sub-states composing the state-vector:

$$\pi(\theta) = \big(\pi_1(\theta), \dots, \pi_i(\theta), \dots \pi_n(\theta)\big) = (|c_1|^2, \dots, |c_i|^2, \dots, |c_n|^2) \quad (3)$$

Each term $\pi_i(\theta)$ can be interpreted as the fraction of state-time, during which the state-vector reamins in the sub-state $|\lambda_i(\theta)\rangle$ and is equal to the square module of the probability amplitude.

Given that the dynamics along the $\theta - axis$ is stationary, the state-probability vector should verify the following steady-state or balance equation:

$\pi(\theta) = \pi(\theta)P(\theta)$ (4)

This expression simply indicates that the distribution of the state-probability vector $\pi(\theta)$ remains stationary for all θ and can equivalently be expressed as follows:

$\pi_j(\theta) = \sum_i \pi_i(\theta)p_{ij}$ where $\sum_i \pi_i = 1.$ (5)

Similarly to the periodic process, the state-time-term $\Delta\theta$ is considered to be dimensionless and normalized (i.e. $\Delta\theta = 1$). Thus, by integrating on the whole term $\Delta\theta$, the probability $\pi_i(\theta)$ for the state-vector to be in a specific sub-state $|\lambda_i(\theta)\rangle$ is given by:

$\pi_i(\theta) = \int h_i\,(\theta)\mathrm{d}\theta$ and $\pi(\theta) = \sum_i \pi_i(\theta) = \sum_i \int h_i\,(\theta)\mathrm{d}\theta$ (6)

The state-time-intervals can be reclassified by grouping together those that are related to the same sub-state. In other words, the state-time-intervals can be distributed into different classes each of which is associated to a specific sub-state. Each class is represented by a set $\Delta\theta_i$ corresponding to the sequence of all (non-overlapping) sub-intervals visited by the same sub-state $|\lambda_i(\theta)\rangle$:

$\Delta\theta_i = \bigcup_j [\theta_{ij} \quad \theta_{i(j+1)}]$ (7)

where each $[\theta_{ij} \quad \theta_{i(j+1)}]$ represents the state-time sub-interval during which the state-vector is found to be in the sub-state $|\lambda_i(\theta)\rangle$ for a corresponding holding state-time $h_i(\theta)$. The measure of the set $\Delta\theta_i$, denoted $\mu(\Delta\theta_i)$, corresponds therefore to the fraction of state-time visited by the sub-state $|\lambda_i(\theta)\rangle$ and is thus equal to $\pi_i(\theta)$. The set $\Delta\theta_i$ simply concatenates all sub-intervals scattered all over the state-time-term $\Delta\theta$ and visited by the same sub-state $|\lambda_i(\theta)\rangle$ and thus enables to express the state-vector $|\psi\rangle$ along the $\theta - axis$.

Indeed, whether the process is periodic or stationary, the state-vector $|\psi\rangle$ of equation (2) can be expressed in function of its sub-states labelled and ordered along the $\theta - axis$ according to the following equation:

$|\psi\rangle = \sum_j c_j\, \delta_\theta(\Delta\theta_j)\, |\lambda_j\rangle$ (8)

where $\delta_\theta(\Delta\theta_j)$ is the Dirac measure (or indicator function) defined as follows:

$\delta_\theta(\Delta\theta_j) = \begin{cases} 1 & if\ \theta \epsilon \Delta\theta_j \\ 0 & if\ not \end{cases}$ (9)

The above equation (8) expresses the state vector as a linear superposition of vector projections in an eigenbasis $\{|\lambda_j\rangle\}$ ordered by the state-time parameter. In other words, it forms a step function made up of a linear combination of Dirac measures of intervals visited by the vector projections.

The wave function $\psi(\lambda_j, \theta)$ associated to the state-vector $|\psi\rangle$ of equation (8) in the basis $\{|\lambda_j\rangle\}$, may thus, be expressed as follows:

$\psi(\lambda_j, \theta) = \langle\lambda_j|\psi\rangle = c_j\delta_\theta(\Delta\theta_j)$ (10)

The above expressions (8, 9, 10) indicate that at any current instant of the physical-time axis, the different sub-states can be viewed as a "state-time-block" wherein, all sub-states or potential outcomes exist but do not occur at once. Indeed, they form a "state-history" labeled by an ordered sequence of "state-dates" in the same manner as the normal history of an ordinary object through ordinary time. The transitions and holding state-times relative to the different sub-states form an "internal-state-clock" that governs the evolution of the system along the $\theta - axis$. The projection of the time-line onto the physical-time axis superposes the different sub-states creating the illusion that the occurrence of all these sub-states is simultaneous when in fact their occurrence is only partially simultaneous (i.e. only with respect to the $t - axis$).

3.3. Measurement

For a given system, the measurement of an observable L in the orthonormal basis of eigenvectors $\{|\lambda_j\rangle\}$ of L is conventionally defined by the following equation:

$$L|\lambda_j\rangle = \lambda_j\,|\lambda_j\rangle \quad (11)$$

where λ_j and $|\lambda_j\rangle$ represent an eigenvalue and the corresponding eigenvector of the Hermitian operator L.

The measurement of the observable L takes place at a specific elementary-time date t_{em} specified by the triplet $t_{em} = (t_m, \eta_m, \theta_m)$. In other words, the measurement should not only be defined with respect to the $t - axis$ but also with respect to the $\eta - axis$ as well as the $\theta - axis$. Indeed, when an event is to be observed it should be done at a particular date and not at a bloc of dates.

In this section, the physical-time t_m and uncertainty-time η_m indices are supposed to be fixed in order to focus only on the state-time index θ.

The state-time index θ along the $\theta - axis$ is considered as a simple index or parameter. However, when time is a dynamical internal variable it can be considered as a time operator [16].

Indeed, for a given system, the internal state-time transitions may be considered as an internal state-clock inherent to that system and is ticking in a domain limited to an interval $\Delta\theta = [\theta_a \;\; \theta_b]$ and wherein the corresponding wave function $\psi(\theta)$ evolves in the domain $\Delta\theta$ and vanishes to zero outside this domain $\Delta\theta$. In order to make a distinction between a simple parameter on the state-time-axis and an inherent state-time-index, the latter is simply called a "state-time-date". The state-time-date is intrinsically related to the time-line of the system and may thus be advantageously considered as a state-time observable associated to a Hermitian operator Θ such that:

$$\Theta|\theta\rangle = \theta|\theta\rangle \text{ for all } \theta\epsilon\Delta\theta. \quad (12)$$

Every real number θ_m in the domain $\Delta\theta$ is an eigenvalue of Θ, and the corresponding eigenvectors are thus given by Dirac's delta functions:

$$|\theta_m\rangle = \delta(\theta - \theta_m) \quad (13)$$

The state of a system is defined at each state-time-date θ_m by a specific wave function $\psi(\theta_m)$ corresponding to the projection of the general wave function $\psi(\theta)$ onto the eigenvector of the state-time-date θ_m according to the following equation:

$$\langle\theta_m|\psi\rangle = \int_{-\infty}^{+\infty} \delta(\theta - \theta_m)\psi(\theta)d\theta = \psi(\theta_m) \qquad (14)$$

Advantageously, the above equation may be used to define the measurement of an observable at any state-time-date θ_m in the domain $\Delta\theta$.

Indeed, let $\Lambda(\theta_m)$ be a measuring operator associated with the observable L of equation (11) defined by $L|\lambda_j\rangle = \lambda_j\,|\lambda_j\rangle$. For $\theta \in \Delta\theta$, the only possible outcomes are the eigenvalues λ_j of the observable L. The probability to find the outcome λ_m before a measurement is conducted at the state-time-date θ_m is given by the square module of the probability amplitude $|c_m|^2$.

However, the action of the measuring operator $\Lambda(\theta_m)$ on the state-vector (i.e. $\Lambda(\theta_m)|\psi(\theta)\,\rangle$) right at the state-time-date θ_m should have the property of selecting the measurement's state-time-date θ_m as well as stopping the internal process of transitions by making the measured outcome an absorbing state. Thus, the action of the measuring operator $\Lambda(\theta_m)$ in terms of wave functions may be expressed as follows:

$$\Lambda(\theta_m)\psi(\lambda_j\,\theta) = L\int_{-\infty}^{+\infty} \delta(c_m(\theta - \theta_m))\psi(\lambda_j\,\theta)d\theta = \frac{L}{c_m}\,\psi(\lambda_m\,\theta_m) = \frac{\lambda_m c_m}{c_m} = \lambda_m \quad (15)$$

The term $\delta(c_m(\theta - \theta_m))$ selects the wave function at the state-date θ_m and divides the corresponding sub-state $|\lambda_m\rangle$ by its associated probability amplitude c_m, thus making the outcome probability equals to 1 stopping hence the mechanism of transitions.

The above equation in terms of the state-vector can be expressed as follows:

$$\Lambda(\theta_m)|\psi(\lambda_j\,\theta)\rangle = L|\lambda_m\rangle = \lambda_m \quad (16)$$

These equations (15, 16) show that at the state-time-date θ_m of the measurement of L, the state-vector was already at a single sub-state $|\lambda_m\rangle$ and thus, the measurement outcome could not be anything else other than the corresponding eigenvalue λ_m of L without any sort of "collapse". The act of measurement simply stopped the internal process of transitions.

The above interpretation can be enlightened by a thought experiment of consecutive tossing of a "quantum" coin. At each time, the coin is thrown into the air so as to rotate several times before it is allowed to land on a table in order to measure the outcome. The whole process of flipping a coin could of course be modeled by classical laws of physics in function of its trajectory and its precession. However, without any physical foundation and only for mere analogical purposes, the spinning motion of the coin in the air is assimilated to a permutation mechanism of transitions between its two faces along a vertical state-time-axis whereas, the consecutive outcomes on the table is assimilated to the evolution of the coin along a horizontal physical-time-axis.

The space of states is a set of two elements "head" and "tail": $\{e_1 = H,\ e_2 = T\}$. The state-vector of the coin can be defined in an orthonormal eigenvector basis composed of two sub-states: $|e_1\rangle = |H\rangle$ and $|e_2\rangle = |T\rangle$ for an observable L consisting of observing the "face-up" side of the coin:

$L|e_j\rangle = e_j\,|e_j\rangle;\ j = 1, 2.$ (17)

According to the conventional interpretation of quantum mechanics, the normalized state-vector of the coin while it is rotating in the air is considered to be in a “superposition” state that can be expressed as follows:

$|\psi\rangle = 1/\sqrt{2}\,|H\rangle + 1/\sqrt{2}\,|T\rangle$ (18)

When the coin falls on the table, there is only a single outcome either head or tail and according to the conventional quantum mechanics, this is interpreted as a collapse of the initial superposed state of the coin into a single sub-state. This misinterpretation comes from the fact that the face-up side of the coin cannot be observed while it is spinning in the air and the coin was supposed to be simultaneously in different states.

However, according to the present interpretation, the face-up side of the coin while it is spinning in the air is accounted for by assigning a “holding-state-time” for each face-up side of the coin. Let $\Delta\theta_H$ and $\Delta\theta_T$ be identical holding-state-times for the two sub-states $|H\rangle$ and $|T\rangle$ respectively. In this case, the normalized state of the flipping coin while it is in the air should be represented as follows:

$|\psi\rangle = 1/\sqrt{2}\,\delta_\theta(\Delta\theta_H)\,|H\rangle + 1/\sqrt{2}\,\delta_\theta(\Delta\theta_T)\,|T\rangle$ (19)

The only possible outcomes are the eigenvalues $|e_1\rangle = |H\rangle$ and $|e_2\rangle = |T\rangle$ of the observable L. The probability to find the outcome $e_m = (e_1 or\ e_2)$ before a measurement is conducted at the state-time-date θ_m is $1/2$.

The outcome can be observed with respect to the physical-time-axis only when the table (i.e., the measuring apparatus) stops the flipping mechanism of the coin. Indeed, only when the coin settles down on the table that can be said whether the outcome is head or tail. Thus, when the coin lands on the table at the landing-state-time-date θ_m, the transition process comes to an end and the measured outcome becomes an absorbing state with a probability equals to 1. In particular, if $\theta_m \in \Delta\theta_H$ (i.e. if the θ-time landing of the coin occurred during the holding time relative to the “H” sub-state), then the measured outcome is “H” otherwise it is “T”.

Thus, by applying equation (15) to the example of the coin, the measuring operator $\Lambda(\theta_m)$ associated with the observable L can be expressed as follows:

$$\Lambda(\theta_m)\psi(\,\theta) = L\int_{-\infty}^{+\infty}\delta(1/\sqrt{2}\,(\theta-\theta_m))\psi(\theta)d\theta = \frac{L}{1/\sqrt{2}}\,\psi(\theta_m) = \begin{cases} H & if\ \theta_m \in \Delta\theta_H, \\ T & if\ not \end{cases} \quad (20)$$

The above equation in terms of the state-vector can be expressed as follows:

$$\Lambda(\theta_m)|\psi(\,\theta)\rangle = \frac{L}{1/\sqrt{2}}|\psi(\theta_m)\rangle = \begin{cases} |H\rangle & if\ \theta_m \in \Delta\theta_H, \\ |T\rangle & if\ not \end{cases} \quad (21)$$

Meanwhile, the consecutive outcomes on the table continue to be governed by a Bernoulli process in the same way that a quantum system continues to be governed by a Schrödinger equation between two measurements along the physical-time-axis.

3.4. Entanglement

Consider a quantum system composed of first and second entangled particles travelling in different directions. Suppose $\{|\lambda_k\rangle\}$ and $\{|\varphi_l\rangle\}$ are two eigenbasis of the first and second particles respectively. The composite state of the quantum system is defined by the tensor product which can be expressed as follows:

$$|\lambda_k\varphi_l\rangle = |\lambda_k\rangle \otimes |\varphi_l\rangle \quad (22)$$

Similarly to equation (8), the state-vector $|\psi(\theta)\rangle$ in the composite space of states of the two particles can be expressed in function of the vector projections in the eigenbasis $\{|\lambda_k\varphi_l\rangle\}$ of an observable L as follows:

$$|\psi(\theta)\rangle = \sum_{klj} c_j\delta_\theta(\Delta\theta_j)\,\left|\lambda_{kj}\varphi_{lj}\right\rangle \quad (23)$$

where as in equation (9), $\delta_\theta(\Delta\theta_j)$ is the Dirac measure that labels and orders the composite sub-states $|\lambda_k\varphi_l\rangle$ along the $\theta - axis$ and where the first and second parts of the ket represent the sub-states of the first and second particles respectively.

The composite sub-states $|\lambda_k\varphi_l\rangle$ do not occur at once. Only one composite sub-state exists at each state-time-date θ and the transition from one composite sub-state into another is governed by the internal-state-clock. Indeed, the internal-state-clock governs the entangled system as a single entity thus, synchronizing the transitions of both particles.

For simplicity, the indices k and l are dropped from equation (23) and the eigenbasis of the composite state is simply written as $\{|\lambda,\varphi\rangle\}$. The wave function $\psi(\lambda_j,\varphi_j,\theta)$ associated to the above state-vector $|\psi(\theta)\rangle$ in the eigenbasis $\{|\lambda,\varphi\rangle\}$, is given by the set of coefficients $c_j\delta_\theta(\Delta\theta_j)$ as follows:

$$\psi(\lambda_j,\varphi_j,\theta) = \langle\lambda_j\varphi_j|\psi\rangle = c_j\delta_\theta(\Delta\theta_j) \quad (24)$$

On the other hand, suppose that $|\lambda_k\varphi_l\rangle$ is an eigenvector of the observable L, with eigenvalue $\lambda_k\varphi_l$, then this can be expressed as follows:

$$L|\lambda_k\varphi_l\rangle = \lambda_k\varphi_l|\lambda_k\varphi_l\rangle \quad (25)$$

Thus, the action of the measuring operator $\Lambda(\theta_m)$ on (for example) the first particle at the state-time-date θ_m, associated with the observable L of equation (25) can be expressed as follows:

$$\Lambda(\theta_m)\psi(\lambda_j,\varphi_j,\theta) = L\int_{-\infty}^{+\infty}\delta(c_m(\theta-\theta_m))\psi(\lambda_j\varphi_j\theta)\,d\theta = \frac{L}{c_m}\,\psi(\lambda_m\varphi_m\theta_m) = \lambda_m\varphi_m \quad (26)$$

The measurement of the observable L is made while the system is in the state $|\lambda_m\varphi_m\rangle$ and thus, as shown by equation (26), the observed value of the measurement is the eigenvalue $\lambda_m\varphi_m$ with certainty.

The entangled system has the same real-time-line but of course, the constituents can move in different directions of space. Each sub-state has its own time-filament associated with both entangled particles. Once a sub-state is detected, it will constitute by itself (after detection) the whole time-line, all other sub-states were not present (either they have already existed or they did not exist yet with respect to the $\theta - axis$) and thus the real-time-line continues to evolve according to the detected sub-state.

The action of measurement on the first particle fixes the outcome for both particles simply because the transitions stop for both particles. In other words, the internal-state-clock synchronizing the transition of states of both particles stops ticking and thus, the action of measurement on any particle fixes the outcome result for both particles. Both particles can thus be considered as "connected" by the same time-filament at each ticking of the internal state-clock.

Consider for example an entangled system of two particles characterized by two spins specified by the z components travelling in opposite directions and emanating from a source midway between two detectors. The composite state of the two-spin system is a tensor product having the following basis vectors [17]:

$|uu\rangle$; $|ud\rangle$; $|du\rangle$; $|dd\rangle$ (27)

where the *u* stands for spin "up" and the *d* for spin "down" and where the first and second parts of the ket represent the states of the first and second particles respectively.

Let the two-spin system be in a maximally entangled state corresponding to the singlet state $|sing\rangle$ expressed as follows:

$$|sing\rangle = c_1|ud\rangle + c_2|du\rangle \quad (28)$$

By taking into account the transitions along the $\theta - axis$, the above expression (28) becomes:

$$|sing(\theta)\rangle = c_1\delta_\theta(\Delta\theta_1)|ud\rangle + c_2\delta_\theta(\Delta\theta_2)|du\rangle \quad (29)$$

As the two sub-states have equal expectations, then $\Delta\theta_1$ and $\Delta\theta_2$ are considered to have the same measure: $\mu(\Delta\theta_1) = \mu(\Delta\theta_2) = 1/2$ and as $|c_j|^2 = \mu(\Delta\theta_j)$ then $c_1 = c_2 = 1/\sqrt{2}$ and equation (29) becomes:

$$|sing(\theta)\rangle = 1/\sqrt{2}\,\delta_\theta(\Delta\theta_1)|ud\rangle + 1/\sqrt{2}\,\delta_\theta(\Delta\theta_2)|du\rangle \quad (30)$$

Thus, making a measurement on the state-vector $|sing(\theta)\rangle$, at state-time-date θ_m and at any location in space is defined by applying onto the state-vector the measuring operator $\Lambda(\theta_m)$:

$$\Lambda(\theta_m)|sing(\theta)\rangle = \begin{cases} |ud\rangle & if\ \theta_m \epsilon \Delta\theta_1 \\ |du\rangle & if\ \theta_m \epsilon \Delta\theta_2 \end{cases} \quad (31)$$

Thus, the measuring operation on either one of the two particles defines the outcome of both particles and the transition mechanism stops, thus, making the measured outcome an absorbing state. In other terms, the internal-state-clock governing the whole system composed of both particles stops ticking and thus, if a measurement is made on the second particle the outcome will be the opposite of what was already measured on the first particle.

Both particles are "connected" by the same time-line composed of an ordered sequence of two time-filaments corresponding to sub-states $|ud\rangle$ and $|du\rangle$ respectively. In other words, the state transition of both particles is synchronized by the same internal-state-clock, and thus, when a measurement is made at either side, the internal-state-clock simply stops the transition into any other sub-state as shown in equation (31).

In order to illustrate entanglement, Susskind [17] gives an example of two classical computers connected by a cable simulating the quantum mechanics of a two-spin system. As long as the computers are connected, entanglement can be simulated but once the computers are disconnected the simulation is destroyed. According to the present model of time, the "connecting cable" can be regarded to be the internal-state-time-clock that synchronizes the transitions of both particles.

The internal-state-time-clock can be tested by conducting an experiment similar to the one realized by Ekaterina [18] illustrating Page and Wootters' mechanism of static time [19, 20]. Ekaterina's experiment implemented the mechanism of static time using the entangled state of the polarization of two photons, one of which is used as a clock to gauge the evolution of the second. An "internal" observer that becomes correlated with the clock photon sees the other system evolve, while an "external" observer that only observes global properties of the two photons can prove it is static. In order to verify the existence of an "internal-state-time-clock", a comparable experiment can possibly be conducted in which the evolution seen by an "external" observer along the physical-time axis is static while the dynamic evolution of the different states along the state-time-axis could probably be correlated to an "internal" observer.

3.5. Evolution along the uncertainty-time-axis

If two operators of a quantum system do not commute, then a state vector $|\psi\rangle$ of one observable cannot be a state vector of the other observable and thus, the result of any "simultaneous" measurement of both observables at any current physical-time instant t is uncertain. However, according to the present model of time, there exists an "internal" mechanism of transitions along the uncertainty-time-axis ($\eta - axis$) between different state-vectors defined in different eigenbasis relative to non-commuting observables. In other words, for a fixed couple of physical-time-index and state-time-index (t_0, θ_0), the state of the quantum system evolves from one chain of sub-states into another. The "internal" mechanism of transitions along the $\eta - axis$ can be represented by a permutation process in a state space defined by a set of different representations of state-vectors relative to non-commuting observables, wherein, each state-vector evolves along the $\theta - axis$ (as described in section 3.2) between its different sub-states $|\lambda_i(\theta)\rangle$ of its corresponding eigenvectors $\{|\lambda_i(\theta)\rangle\}$.

The evolution of a quantum system $|S\rangle$ along the $\eta - axis$ can thus be defined as follows:

$$|S\rangle = \sum_k \delta_\eta(\Delta\eta_k)\,|\psi_k\rangle \quad (32)$$

where $\delta_\eta(\Delta\eta_k) = \begin{cases} 1 & if\ \eta \in \Delta\eta_k \\ 0 & if\ not \end{cases}$ and $|\psi_k\rangle = \sum_k c_{kj}\delta_\theta(\Delta\theta_{kj})\,|\lambda_{kj}\rangle$. (33)

Thus, the evolution of the quantum system $|S\rangle$ in the time-plane $(\eta,\ \theta)$ can be defined as follows:

$$|S\rangle = \sum_{kj} \delta_\eta(\Delta\eta_k) c_{kj} \delta_\theta(\Delta\theta_{kj})\,|\lambda_{kj}\rangle \quad (34)$$

In view of the above, it is clear that no measurement can be realized "simultaneously" with respect to two non-commuting observables simply because the state vector $|\psi\rangle$ of one observable cannot exist at the same uncertainty-date as the state vector $|\psi\rangle$ of another non-commuting observable. There can only be a "partial simultaneity" with respect to a physical-time-date and a state-time-date (t_0, θ_0) where only one conjugate variable exists and can be measured but there can never be a "total simultaneity" with respect to a global date including an uncertainty-index and thus, there can never be "total simultaneous" measurement of non-commuting observables.

In general, the measurement of the quantum system $|S\rangle$ with respect to an observable A at a specific "global-time-date" (t_m, η_m, θ_m) where the physical time index t_m is considered to be initially fixed, may be expressed by the action of a corresponding measuring operator $\Lambda(\eta_m, \theta_m)$ on the wave function $\psi(t_m, \eta, \theta)$ as follows:

$$\Lambda(\eta_m, \theta_m)\psi(t_m, \eta, \theta) = A \int_{-\infty}^{+\infty} \delta(c_m(\theta - \theta_m))\delta(\eta - \eta_m)\psi(t_m, \eta, \theta) d\theta \quad (35)$$

and thus:

$$\Lambda(\eta_m, \theta_m)\psi(t_m, \eta, \theta) = \frac{A}{c_m}\psi(t_m, \eta_m, \theta_m) \quad (36)$$

Thus, the action of the measuring operator $\Lambda(\eta_m, \theta_m)$ on the wave function $\psi(t_m, \eta, \theta)$ selects the measurement's uncertainty-time-date η_m and state-time-date θ_m and stops the internal process of transitions.

3.6 Estimation of time-thickness

As indicated in section 3.3, the state-time-date may be considered as a state-time observable associated to a Hermitian operator Θ according to equation (12). The state of a system is defined at each state-time-date θ_m by the specific wave function $\psi(\theta_m)$ of equation (14).

A Hermitian energy operator H can thus be defined with respect to the state-time-axis and its action on the wave function $\psi(\theta)$ may be represented as follows:

$$H\psi(\theta) = -i\hbar\, \partial\psi(\theta)/\partial\theta \quad (37)$$

The eigen-equation can be expressed as follows:

$$-i\hbar\, \partial\psi_E(\theta)/\partial\theta = E\psi_E(\theta) \quad (38)$$

where E and $\psi_E(\theta)$ are the eigenvalue and eigenvector respectively of the Hermitian energy operator H. The solution of the above equation is given by the following expression:

$$\psi_E(\theta) = \frac{1}{\sqrt{2}} e^{\frac{iE\theta}{\hbar}} \quad (39)$$

Therefore, the period along the state-time axis with respect to equation (39) is:

$$\Delta\theta = 2\pi\hbar/E \quad (40)$$

The same kind of analysis can be made concerning position and momentum with respect to the uncertainty-time-axis. In that case, the wave length is defined as:

$$L = 2\pi\hbar/p \quad (41)$$

and thus, the period along the uncertainty-time axis may be estimated to be:

$$\Delta\eta = L/c = 2\pi\hbar/cp \quad (42)$$

Thus, time-thickness of a physical system depends on its energy and momentum which can be determined by the Schrodinger equation along the physical-time-axis.

For a given state-vector $|\psi\rangle$, the thickness of its corresponding real-time-line depicts a more logical representation of quantum phenomena such as "wave function collapse", entanglement and uncertainty.

However, time-thickness for macroscopic phenomena is very small to be noticeable and can be neglected. Nevertheless, it becomes important for short living phenomena and in particular, at the early stage of the universe where it should be taken into consideration as it will be seen in the next section.

4. Cosmic features of a dynamical time-line

The thickness of time is very small to be noticeable in a macroscopic universe. However, in a microscopic universe or in other words, at the beginning of the universe, the thickness of time should not be neglected. Indeed, as the physical-time tends to zero, the measures of state-time and uncertainty time should have been comparable to that of the physical-time and at a very early stage should have even been bigger than the physical-time owing to the fact that state and uncertainty times are internal clocks. Therefore, in order to understand the phenomena that took place at the beginning of the universe, time-thickness should be taken into consideration.

In order to illustrate the effect of time-thickness, the global-time-tube metric of equation (1) should be used to generate an appropriate spacetime metric.

The approach explained by Carroll [21] is used to derive an appropriate metric that takes into consideration the above element of the global-time-tube. A spatially homogenous and isotropic Universe evolving within a global-time-tube can be represented at each point of the global-time-tube by spacelike three-dimensional slices such that each slice is maximally symmetric. Thus spacetime is considered to be $\boldsymbol{R^3\Sigma}$ where $\boldsymbol{R^3}$ represents a three-dimensional time metric and $\boldsymbol{\Sigma}$ is a maximally symmetric three-dimensional space metric. The six-dimensional spacetime can thus be expressed by the following sort of Robertson-Walker metric:

$$ds^2 = -dt_G^2 + a^2(t_G)d\sigma^2 \qquad (43)$$

where t_G is the global-time-tube, $a(t_G)$ is a dimensionless scale factor and $d\sigma^2$ is the metric on $\boldsymbol{\Sigma}$.

The above metric of equation (43) obeys the following Friedman equations:

$$H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} \qquad (44)$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) \qquad (45)$$

where a is the scale factor that stands for $a(t_G)$, H is the Hubble parameter, G is the gravitational constant, ρ is the energy density, k is the spatial curvature, and p is the pressure. Friedmann equation (44) can equivalently be written in the following form:

$$|\Omega - 1| = \frac{|k|}{a^2H^2} \qquad (46)$$

where Ω is the density parameter measuring the ratio between the density and the critical density and where a flat space is represented by $\Omega = 1$ [13, 20].

For simplicity, the time-tube is restricted to the plane $(t,\ \theta)$ which would be enough to illustrate the effect of time-thickness on the expansion of the universe.

In that case, by taking into consideration the metric of equation (1), an element of the global-time-tube in the plane $(t,\ \theta)$ at the beginning of the big bang (i.e., *t* being very small) may be expressed as follows:

$$t_G{}^2 \sim t^2 + \theta^{\,2} \quad (47)$$

After introducing, the above element of the global-time-tube, the scale factor for a universe dominated by only one kind of energy density (which indeed should have been the case at the beginning of the universe) is given by the following relation:

$$a \propto t_G{}^{2/n} \sim (t^2 + \theta^{\,2})^{1/n} \quad (48)$$

Differentiating the above expression with respect to the physical time *t* gives:

$$\dot{a} \propto \frac{2t}{n}(t^2 + \theta^{\,2})^{1/n-1} \quad (49)$$

Differentiating again with respect to *t* gives:

$$\ddot{a} \propto \frac{2\left(t^2+\theta^2\right)^{1/n-2}}{n}\left(\theta^{\,2} - \frac{n-2}{n}t^2\right) \quad (50)$$

The first term is positive and thus:

$$\ddot{a} > 0 \text{ when } t < \sqrt{\frac{n}{n-2}}\theta \quad (51)$$

$$\text{Let } \tau = \sqrt{\frac{n}{n-2}}\theta \quad (52)$$

where τ represents the physical time below which, the Universe was in an inflation-era.

Introducing the estimation of time-thickness of equation (40) into equation (52) gives:

$$\tau = 2\pi\hbar\sqrt{\frac{n}{n-2}}/E \quad (53)$$

At the beginning, the universe was radiation-dominated (i.e. n=4, $p = {}^{\rho}/_{3}$) and thus the inflation era is given by:

$$\tau = 2\sqrt{2}\pi\hbar/E \sim h/E \quad (54)$$

Equation (54) gives an estimation of the inflation era in function of the energy at the beginning of the Universe.

On the other hand, by substituting $\ddot{a} > 0$ into the Friedmann equations (44, 45), the following inequalities are derived :

$$p < {}^{\rho}/_{3} \quad (55)$$

$$\frac{d\left(H^{-1}/a\right)}{dt} < 0 \quad (56)$$

In particular, relation (56) forces the value of Ω in equation (46) to 1 which solves the flatness problem. This scenario explains the observed flatness and isotropy of the Universe without the need to introduce any kind of "dark energy".

However, according to this scenario, the space inflation seems to be more of an illusion and it simply results out of observing the inflation-era with respect to the very small scale ($t < \tau$) of the physical-time axis. Indeed, for $t < \tau$, the length of the global-time-tube t_G is greater than that of the physical time t ($t_G \sim \sqrt{t^2 + \theta^2} > t$) and thus, the real period of time is greater than that of the physical time. In other words, the expansion of the universe during the inflation era lasted more than what would be expected by an observer who traces the history only along the physical-time axis.

On the other hand, for $t \geq \tau$, $\ddot{a} \leq 0$ and thus, the inflation stops at $t = \tau$ and the acceleration decreases for $t > \tau$.

For $t \gg \tau$, the projections of the global-time-tube on the state-time-axis and on the uncertainty-time-axis can be neglected as they are very small compared to that on the physical-time axis. The global-time-tube can simply be approximated by its projection on the physical-time axis (i.e. $t_G \sim t$). Thus, far from the inflation-era the global-time-tube behaves almost as the familiar physical time.

However, depending on the energy density of the universe, the curvature of spacetime should affect the dynamical relation between the different components of time. In other words, the global-time-tube becomes more or less curved and this in its turn should affect the apparent rate of expansion of the universe. For example, if the "length" of the global-time-tube is greater than its projection on the physical-time axis, then the universe would seem to be spatially inflating if the physical-time-axis is the only one to be considered and not the real "length" of the global-time. The present observations seem to indicate that the universe is inflating and this apparent inflation could be simply explained by the dynamic nature of time without the need to introduce any kind of black energy. Indeed, many papers questioned the foundations of black energy. In particular, Gibson [22, 23] have showed that dark energy seems to be in contradiction with fluid mechanics. Thus, an alternative fluid mechanically based cosmology HGD (hydro-gravitational-dynamics) has been proposed by Gibson and Schild [24] where dark energy and dark matter are not necessary to explain the expansion and structure formation of the Universe. Moreover, HGD predicts a different rate of formation of galaxies and black holes [25] than the standard model.

5. Conclusion

This dynamic nature of time "reconciles" the different interpretations of quantum mechanics. Indeed, a "collapse of a wave function" becomes "halting inner transitions", "multi worlds" become "multi-real-time-filaments" and finally "hidden variables" become "internal-clocks" or "time-thickness". On the other hand, time-thickness and the dynamic nature of time also explain some cosmological features such as space flatness and isotropy of the universe.

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