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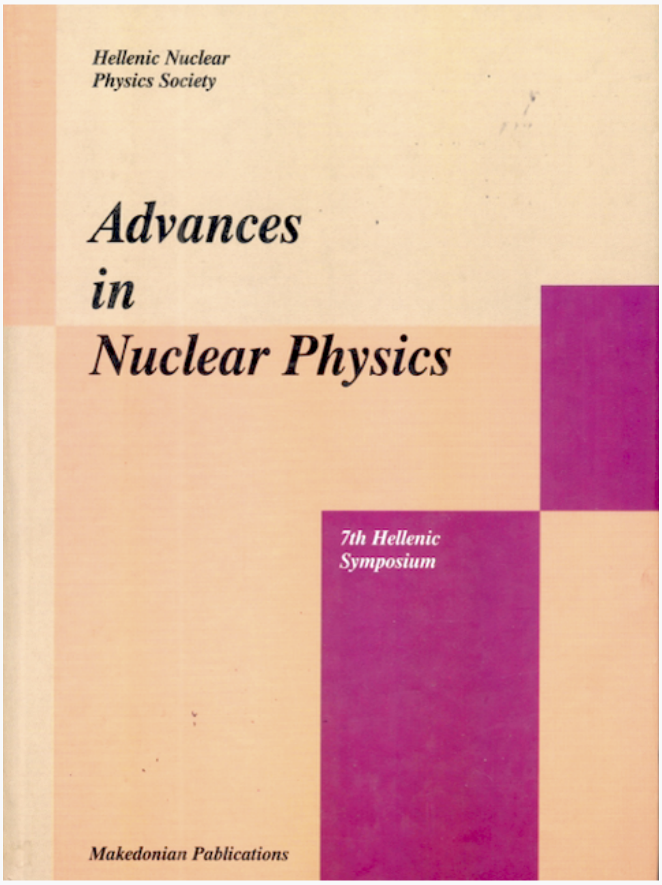

Quantum chrono-topology of nuclear and sub-nuclear reactions - The measurement problem

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Quantum chrono-topology of nuclear and sub-nuclear reactions - The measurement problem

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Abstract

The conventional tacit assumption that nuclear and sub-nuclear reactions take place in the Newtonian universal time is replaced in the present paper by a time topological space based on the interaction proper time neighbourhood. It is developed and used to solve a problem related to the nuclear reaction theory, the quantum measurement problem. The time topology is disconnected and satisfies the separation axioms of the topological space $\mathcal{T}_4$. In this topology the ***U+R*** Penrose dynamics is implemented by means of a time evolution operator, $\mathcal{U}_{nmp}$, constructed using a quantized version of Gel'fand's theory - the generalized random quantum field theory ($QRQFT$). As an application the quantum measurement problem solution is presented.

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I Introduction

The explanation of the disaccordance[1,2] between the time reversal invariance of the basic equation of physics, like the Schroedinger, the Dirac equations and the quantum field theories (QFT) and the overwhelming majority of the macroscopic phenomena makes up a great part of the first line research activities during the last decades all over the world.On the other hand the discovery of chaos phenomena also in nuclear physics [3] induced the idea to many researchers that chaos and irreversibility may be connected by means of a not yet discovered fundamental relationship.

These developments seen in relation with the persisting well-known paradoxes of quantum theory make clear that possibly a fundamental concept in physics has been ill-defined and it must be revised [4].

The time idea attracted since long the attention of many researchers. Various new time models [5] have been proposed. None of them has been decisively advanced to a the position to explain the open issues of quantum theory.

In a series of papers [6] the idea of a new time topology was advanced and interesting results were obtained, like the derivation of statistical mechanics from QFT in Minkowski' s metric among others.

The purpose of the present paper is to apply chrono-topology and give a solution of the mesurement problem of quantum theory in nuclear physics. The chrono- topology implies that the physical fields on the quantum level become generalized random and infinitely divisible [7].

In the next section II the fundamentals of the new time topology and some useful definition are presented in order to facilitate the understanding.

II The time topology in quantum physics

In order to make precise the description and to facilitate the understanding, it is expedient to give first some notation and some definitions from general topology which are required for the presentation of the results.

Let a set $\mathcal{T}$,called the space, be given with a family $\{\tau\}$ of subsets $\tau \subseteq \mathcal{T}$ together with the empty set $\varnothing$. The elements of $\mathcal{T}$ are called points of the space and the elements τ are called open sets.

Definition 1

A pair $(\mathcal{T}, \tau)$ of $\mathcal{T}$ *and* τ *represents a topological space, if the following conditions are satisfied* [8]:

(i) $\varnothing \in \tau$ *and* $\mathcal{T} \in \tau$.

(ii) *If* $U_1 \in \tau$, *and* $U_2 \in \tau$, *then* $U_1 \cap U_2 \in \tau$.

(iii) *If* $\mathcal{A} = \{A_1, A_2, ...\}$ *is a family of elements of* τ *and I is a subset of the index set J such that* $A_i \in \tau$, $\forall i \in I$, *then* $\bigcup_{i \in J} A_i \in \tau$.

It is clear that the intersection $\bigcap_i A_i$ of a finite subset $\{A_i\ i \in I \subseteq J\}$ of open subsets is open.

Definition 2

A space, $\mathcal{T}$, *is called regular if and only if for every* $x \in \mathcal{T}$ *and every neighbourhood* $\mathcal{V}$ *of x in a fixed subbase* $\mathcal{P}$ *there exists a neighbourhood U of x such that* $\mathcal{U} \subset \mathcal{V}$, *where* $\mathcal{U}$ *is the closure of U.*

The topological spaces may be ordered in a hierarchy according to the restrictions which are imposed on them. These restrictions are called *axioms of separation.* Here are the axioms of separation concerning the fundamental interactions physics:

Definition 3

0. *A topological space,* $\mathcal{T}$, *is called a* $\mathcal{T}_0$*-space, if for every pair of distinct points* $t_1, t_2 \in \mathcal{T}$ *there exists an open* τ' *containing exactly one of these points.*

1. *A topological space,* $\mathcal{T}$ *is called a* $\mathcal{T}_1$ *-space, if for* every pair of distinct points $t_1, t_2 \in \mathcal{T}$ *there exists an open* $\tau' \subset \mathcal{T}$ *such that either* $t_1 \in \tau', t_2 \notin \tau'$ or $t_1 \notin \tau', t_2 \in \tau'$.

2. *A topological space,* $\mathcal{T}$, *is called a* $\mathcal{T}_2$*-space, or a Hausdorff space, if for every pair of distinct points* $t_1, t_2 \in \mathcal{T}$ *there exist open sets* $\tau_1, \tau_2 \subset \mathcal{T}$ *such that* $t_1 \in \tau_1$, $t_2 \in \tau_2$ and $\tau_1 \cap \tau_2 = \varnothing$.

3. *A topological space,* $\mathcal{T}$, is *called a* $\mathcal{T}_3$ *-space or a regular space, if it is a* $\mathcal{T}_1$ *-space and for every* $t \in \mathcal{T}$ *and for every closed se*t $\mathcal{F} \in \mathcal{T}_3$ *such that* $t \notin \mathcal{F}$ *there exist open sets* τ_1, τ_2 *such that* $t \in \tau_2$, $\mathcal{F} \in \tau_2$ *and* $\tau_2 \cap \tau_2 = \varnothing$.

4. *A topological space,* $\mathcal{T}$, is *called a* $\mathcal{T}_4$*-space or a normal space,* if $\mathcal{T}$ *is a* $\mathcal{T}_1$ *-space and for every pair of disjoint closed subsets* τ_1, τ_2 *there exist open sets U and V such that* $\tau_1 \subset U$, $\tau_2 \subset V$ *and* $U \cap V = \varnothing$.

Clearly, a $\mathcal{T}_4$-space is a $\mathcal{T}_3$-space so that the hierarchy hold*s* :

$$\mathcal{T}_0 \Rightarrow \mathcal{T}_1 \Rightarrow \mathcal{T}_2 \Rightarrow \mathcal{T}_3 \Rightarrow \mathcal{T}_4$$

III Time generation in quantum physics

By "mixing" the time and the space variables, as it happens in the Lorentz transformation, we do not yet fully eliminate the classical, absolute character of the time. Such should be achieved better by attaching to every single nuclear reaction its own time neighbourhood.This time neighbourhood contains values corresponding exactly to observables changing as long as the interaction is going on.

Considering that in a nucleous each nucleon's history is described by its own set of time neighbourhoods - each one starting and ending with the starting and the ending of the corresponding interaction (causing associated changes in observables of the pertinent nucleon) it is not obvious at first sight, which one of the many «pieces» of time (which, by the way, clearly may overlap partially or entirely,in the sense of the relativistic simultaneity) would be appropriate to describe the nucleus as a physical system.This difficulty is avoided by introducing the notion of the *IPN*.

In conformity with the above ideas we shall prove the following

III.1 The time as a map of the observables changes

Proposition 1

The changes $(\Delta x', \Delta t')$ of the coordinates (x', t') in observer's moving reference system of an event (x,t) in its rest system of reference are linear functions of the changes $(\Delta x, \Delta t)$.

Proof

Consider the Lorentz transformation:

$$x' = \gamma .(x - v.t) \tag{3}$$

$$t' = \gamma .(t - \beta /c.x) , \tag{4}$$

where $\gamma = 1/\sqrt{(1-\beta^2)}, \beta=v/c$.

Let $x = 0$ in (3). Any change, Δt, of the time, t, is a linear function of the change $\Delta x'$ of x'.

The converse is also true: It follows from (4) that the change $\Delta t'$,of the time, t', for $t = 0$ is a linear function of the change, Δx, of the space variable,x, and vice versa.

Therefore

$$\Delta x' = -\gamma \; v.\Delta t , \tag{5}$$

$$\Delta t' = - \gamma \; \beta /c. \; \Delta x \tag{6}$$

and the proof is complete.

Remark 1

This obvious and rather trivial result is known to many people since almost one century. However, its special meaning seems to have escaped hitherto our attention: If we convene to consider the coordinate x as an observable, then (5) is a *regular, continuous map* of the change of an observable to a linear set, the ***interaction proper time neighbourhood.***

Table I. *Orders of magnitude of the IPNs for QED and QCD following from (5- 6) and the magnitudes of atoms and nuclei (β=v/c)*

Theory	β	approx. radius [m]	set diameter $\delta(\tau)$ [s]
QED	.1	10^{-10}	10^{-19}
QCD	.1	10^{-15}	10^{-24}

In addition, Δx represents in physics the displacement of, e.g., a particle. By generalizing this to any observable change one obtains a map of the changes onto the time-space. This is a generalization of ***Proposition 1*** .

III.2 The construction of the time-space topology

The ***Axioms I*** to ***III*** are considered as the cornerstones of the present new chrono-topology and are based on the following ***Definitions 1 and 2.***

Axiom I.

All time definitions, classical or quantal, are based on some process implementing a change of an observable, natural or technical and generates a time neighbourhood. The generated time neighbourhood (IPN) is a regular into-map of just this change.

Axiom II.

Every fundamental interaction is associated with (different among them, but) a finite change of the related physical observable. Sets of observables' changes have intrinsic the random character, as to their embedment in the Newtonian time. They start at irregular Newtonian times and have, within limits, stochastically distributed durations. They may be thought of as embedded in the Newtonian universal time, R^1, but their union has not the topology of R^1.

Axiom III

The elements of the empty set, $\varnothing$, of a class of sets $\{O_\lambda | \lambda \in Z^+\}$ of observables, O_λ, are not observable, and their values are identically equal to zero.

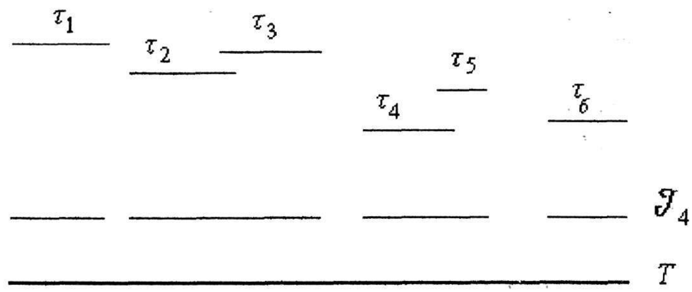

Fig. 1. Representation of six IPNs $\{\tau_i | i = 1,2,...6\}$, *the union,* $\mathcal{T}_4$, *of their projections, and a subset,* $T \subset R^1$, *of the Newtonian universal time,* R^1, *in which* $\mathcal{T}_4$ *may be considered as embedded.*

Here is the principal definition of the *interaction proper-time neighbourhood*, the *IPN*:

Fundamental Definition 4

Let O_λ *be an observable characterizing one or both particles of a given pair of interacting quanta.*

Let ΔO_λ *be the corresponding change due to a fundamental interaction. We define the IPN (interaction proper- time neighbourhood) as the regular and continuous map:*

$$\tau_\lambda = IPN = f : \Delta O_\lambda \to \tau_\lambda = f(\Delta O_\lambda) \in \mathcal{T}_4. \qquad (7)$$

IPN is a time "quantum" of the process corresponding to the fundamental interaction under consideration, characteristic ***of*** *and proper* ***to*** *that interaction and only to that.*

III.3 The many-folded super space-time

Definition 5

1. Let $K \times \Lambda_K$ *pairs of quanta interact.*

2. Let $\{T_\kappa | \kappa \in [1, K] \equiv I_K \subset Z^+\}$ *be a family of subsets* $T_\kappa \subset R^1$ *such that*

$\{T_\kappa \cap T_{\kappa'} = \emptyset | \forall(\kappa, \kappa') \in I_K \subset Z^+\}$.

3. Let $\{\tau_{\kappa\lambda_\kappa} \in T_\kappa, \forall\lambda_\kappa \in [1, \Lambda_K] \equiv I_{\Lambda_K}, \kappa \in I_K\}$ *be a family of IPNs such that*

$\{\tau_{\kappa\lambda_\kappa} \cap \tau_{\kappa\lambda'_\kappa} = \varnothing \ for \ \lambda_\kappa \neq \lambda_\kappa'\}$.

We define:

i) The Λ_K *-fold,disconnected time-space by*

$$\mathcal{T}^{(\Lambda_\kappa)}_4 = \tau_{\kappa 1} \oplus \tau_{\kappa 2} \oplus \ldots \oplus \tau_{\kappa\Lambda_\kappa} \ , \tag{8}$$

$\{\delta(\tau_{\kappa\lambda_\kappa})\}$ *may be thought as the random absolute values of vectors orthogonal at every point of Riemann space-like super-surfaces.*

ii) The Λ_κ *-fold,disconnected superspace-time in the sense of* Λ_κ *-fold Riemann superspace-time by*

$$\overline{M^4_{\Lambda_\kappa}} = (\tau_1 \oplus \tau_2 \oplus \ldots \oplus \tau_{\Lambda_\kappa}) \times R^3 \ , \tag{9}$$

where R^3 *is a 3-dimensional Riemann space .*

The formulation of a physical theory in terms of generalized random and infinitely divisible fields requires appropriate space-time structures of the above form for the existence of conservation laws.

To make this clear, let us consider one single *IPN*, τ_1, and the corresponding space-time, $\overline{M^4_{\kappa 1}}$. The lower index signifies that $\overline{M^4_{\kappa 1}} = i\tau_{\kappa 1} \times R^3$, and this spacetime is simple in time, i.e., a subset of a Riemann space. If R^3 is flat, then $\overline{M^4_{\kappa 1}}$ becomes a subset of the Minkowski space.

If there are two different *IPN*s, such that on the one hand $\tau_1 \cap \tau_2 = \varnothing$ and,on the other hand their projections π_1, π_2 into T_κ satisfy $\pi_1 \subseteq \pi_2$, then the corresponding space-time is $\overline{M^4_2} = i(\tau_1 \oplus \tau_2) \times R^3$. This space-time is *two-fold in time*.

In case $R^3 = E^3$, the Euclidean 3-space, M^4_2, is not a subset of Minkowski's space anymore.

It is said in terms of relativistic simultaneity fully or partly simultaneous according to the relations

$$(\pi_1 \subseteq \pi_2) \wedge (\pi_1 \supseteq \pi_2) \text{ or } (\pi_1 \subseteq \pi_2) \vee (\pi_2 \subseteq \pi_1)$$

respectively.

More generally,if λ_κ *IPN*s satisfy

$$\tau_\lambda \cap \tau_{\lambda'} = \varnothing, \forall (\lambda, \lambda') \in I_\kappa$$

and their projections into T_κ

$$(\pi_\lambda \subseteq \pi_{\lambda'}) \wedge (\pi_\lambda \supseteq \pi_{\lambda'}) \text{ or } (\pi_\lambda \subseteq \pi_{\lambda'}) \vee (\pi_{\lambda'} \subseteq \pi_\lambda), \ \forall (\lambda, \lambda') \in I_\kappa,$$

then the structure of $\overline{M^4_{\kappa\lambda_\kappa}}$ is even higher.

In a λ_κ- fold in time space-time the decomposition of divisible field $\mathcal{L}$ in up to λ_κ terms is possible without interfering neither with the definition of the function notion nor with conservation laws of physics,cases in which,for example, $f(x) \neq 2f(x)$. An illustration of our time-space $K = 4, (\Lambda_1 = 1, \Lambda_2 = 2, \Lambda_3 = 2, \Lambda_4 = 1)$ is given in Fig. 1, while the case $K=3$ $(\Lambda_1 = 2, \Lambda_2 = 3, \Lambda_3 = \kappa)$ time-space is shown in Fig. 2 .

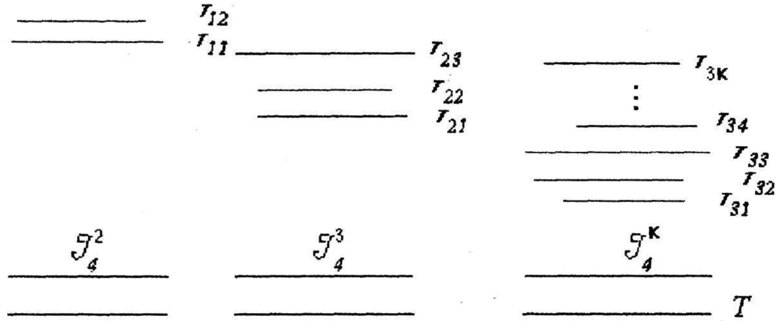

Fig. 2. Three types of many - folded topological time-spaces: Two - fold, $\mathcal{T}_4^2$ *, three-fold,* $\mathcal{T}_4^3$ *and* κ*-fold,* $\mathcal{T}_4^\kappa$ *.These time-spaces give rise to the creation of the space-times,* $\overline{M}_{12}^4, \overline{M}_{23}^4, \overline{M}_{3\kappa}^4$.

It is important that the time in ,e.g., the rest frame of a particle is related to its corresponding interaction. If to all *IPN*s were given the properties of one single *IPN*,the time-space would lose its randomness.

We put just this time in the equations of Schroedinger,of Dirac and of *QFT* in connection with problems of nuclear and sub-nuclear interactions. The time change within an IPN cannot generate the impression of flowing: i) It escapes the discrimination power of the human sensors. ii) There is one single *IPN* and no ordering is feasible.
On the contrary,for a moving observer the reaction time may flow or not flow further depending, according to (4) above, on whether the particle changes either its position, x, or its time, t, or both, or any other of its observables. Hence, it is clear that the particle reaction time cannot be identified with the universal time which is the union of the maps of all observable changes occurring in the entire observable universe.

Remark 2

The factor $\mathcal{T}_4$ determines the structure of the new space-time $\overline{M}_{\kappa\lambda_\kappa}^4$. The space-time, $\overline{M}_{\kappa\lambda_\kappa}^4$, $\kappa\times\lambda$ -fold in time is the natural space-time for the application of the theory of the generalized and inifinitely divisible fields .

Remark 3

Time-dependent quantum equations not including interactions do not supply us with any physical information with respect to the evolution of the particle system. For example,an electron moving in vacuum without interaction is described by free field quantum time - dependent equations, but it does not exist. It is not observable, if it does not interact.

However, the situation is still more complex: The kind of time topology nature chooses in every individual case of interacting particle systems, depends on the number of the interacting particle pairs and on whether the interactions are partially or totally simultaneous in the sense of relativity. One easily realizes based on our definition of the time, that the topological space, $\mathcal{T}_4$, tends to the space with the *natural* topology of R^1, if the number of the interacting particles becomes very large and the intersections of the adjacent *IPN*s are not empty anymore [9]. More precisely:

$$\{ (\mathcal{T}_4 \rightarrow natural\ topology\ of\ T_{K1} \rightarrow R^1) \wedge (\overline{M}^4_{K1} \rightarrow M^4)\ for.K \rightarrow Z^+ \} \quad (10)$$

$\overline{M}^4_{K1}$ *is the physical space-time created by the dynamics and yields the scenery for the evolution of the dynamical particle systems.*

M^4 ,Minkowki's pace-time,is a mathematical construction representing the limit $\overline{M}^4_1$ of an infinity of interacting particles, such that $\{\tau_\lambda | \forall\lambda \in \Lambda \rightarrow Z^+\}$ is a covering basis of R^1 (no simultaneous interactions).

IV.1 Chrono-topology and irreversibility considerations

The chrono-topology opens new possibilities for the investigation of the ***U*** and ***R*** kinds of time evolution. We continue here the examination of these aspects.

i) The fundamental equations of physics- icluding interactions - as well as the phenomena described by them are time-reversal invariant on every single *IPN*, τ .The conservation laws are valid for ***U*** processes.All phenomena are time reversible inside one and the same *IPN*, τ , during ***U*** time evolution.

ii) But (attention!) the event that the *time-reversed interaction action-integral* equals the action - integral of the (factual) reverse interaction has a zero probability measure.

The probability measures for these processes have the following properties:

i) The measure, μ_{Direct} ,for the direct process is associated with a mathematically realizable and physically possible process.

ii) The measure, $\mu_{Time-reversed}$,for the time-reversed process is associated with a mathematically realizable and physically (in the same τ) impossible process.

iii) The measure, $\mu_{Reverse\,interaction}$, for the reverse interaction corresponds to a process both mathematically and physically possible. It is important to realize, however,that a mathematically time reversed and the factually reverse reactions do not take place in the same τ .

The combination of the measures have the properties:

$$\mu_{Direct}, \mu_{Time-reversed}, \mu_{Reverse\,interaction} > 0,$$
$$Probability\ measure\{\mu_{Direct} = \mu_{Reverse\,interaction}\} = 0,$$
$$Probability\ measure\{\mu_{Direct} = \mu_{Time-reversed}\} = 1.$$

These relations can become more clear with the help of three,generally, different well-ordered *IPNs* $\{\tau_1 \succ \tau_2 \succ \tau_3\}$. Suppose that the direct and the time-reversed reactions take place for $t \in \tau_2$. Since the factually reverse reaction cannot proceed simultaneously with the direct reaction, it will take place either in $t \in \tau_1 \succ \tau_2$ or in $t \in \tau_3 \prec \tau_2$.

This expresses the physical fact that

$$\{TIME\text{-}REVERSED\ REACTION \int dt\, H(t)\ ,\ t \in \tau_2\}$$

$$\neq \{\int dt\, H(t)\ of\ the\ REVERSE\ \ REACTION\ ,(t \in \tau_1 \succ \tau_2) \vee (t \in \tau_3 \prec \tau_2)\}.$$

The above relation (i.e., "*mathematically time-reversed reaction" is different from the "action of the factually reverse reaction")* is true, because the *IPNs* $\{\tau_1, \tau_2, \tau_3\}$ may be different in two respects:

1) As sets.
2) As set diameters, $\{\delta(\tau_\lambda), \lambda = 1,2,3\}$.

On the other hand, the ranges of any functions in $\{\tau_1, \tau_2, \tau_3\}$ are, with high probability, different at least for two reasons:

i) $\delta(\tau_\lambda), \lambda = 1,2,3$,as numbers: $Probability\ measure\{\delta(\tau_i) = \delta(\tau_j), j \neq i\} = 0$,

and

ii) $\tau_\lambda, \lambda = 1,2,3$ as point sets: $Probability\ measure\{\{\tau_i\} \cap \{\tau_j\} = \varnothing\} = 1, j \neq i$.

IV.2 Planck time and chrono-topology

Despite the differences between our space-time topology in the conception and in the construction method and the space-time foam of S. Hawking [10] there is, nevertheless, a certain resemblance in the limit $\delta(\tau_\lambda) \to$ *Planck time,* $\forall \lambda \in Z^+$, when the interactions become very fast.

If the «foam» time intervals had all the Planck time magnitude, they would loose their random character.

If the observers lived in τ, it would be impossible to compare $\tau_j\, with \tau_i$ for $j \neq i$. Because each τ_λ is its own unit in the rest frame. However,such a comparison is for the human observers perfectly possible,because our senses are exposed to quanta coming from many different,but,more or less,overlapping interactions in $T \subset R^1$,due to our ability to observe (almost) simultaneously more than one physical changes.

The time space topology $\mathcal{T}_4$ introduced above bears *intrinsically the random character of the IPNs*. It is this property that imposes randomness to every function of the time. An important observation is that the randomness can be perceived by the observers, because they are living in the background of the Newtonian time which has the topology of R^1.

Some examples of functions defined in τ becoming random in $\mathcal{T}_4$ are :

i) The *space-time coordinates for the moving observer of a particle system*. The observers are almost in all cases moving with respect to the interacting elemen-

tary particles, so that observation is mediated by Lorentz transformations.
ii) All *observables expressed as functions of the space-time coordinates* in the *rest frame of reference of the observer.*
iii) The *components of the quantum fields* which become generalized random fields.
iv) The *Hamiltonian and the Lagrangian densities* become generalized random and infinitely divisible fields, thus admitting the representation

$$F(\varphi(x),\partial\varphi(x)) = F(\varphi(x_1),\partial\varphi(x_1)) + F(\varphi(x_2),\partial\varphi(x_2))+...+F(\varphi(x_{\Lambda_K}),\partial\varphi(x_{\Lambda_K})),$$

$\kappa = 2,3,...$ and $\lambda_\kappa = 1,2,...\Lambda_K$ for $x \in \overline{M}^4_{\kappa\lambda_\kappa}$.

for $\kappa, \lambda_\kappa \in Z^+$ and with *probability distributions independent of* κ, λ_κ.
v) The *metric tensor* $g_{\mu\nu}$ *of the space-time* in General Relativity.

The *IPN*s, as maps of finite observables' changes through interactions, they are compact in R^1 ,and their set diameters are empirically inversely proportional to the strength of the interaction.

V.1 The wave function reduction in nuclear measurements

Let us now see Penrose's most clear view in the matter of the problem [4]:
" *The quantum measurement problem is to understand, how the procedure* ***R*** *can arise - or effectively arise - as a property of a large - scale behavior in* ***U****-evolving quantum systems. The problem is not solved merely by indicating a possible way in which an* ***R****-like behavior might conceivably be accommodated. One must havea theory providing some understanding of the circumstances under which (the illusion ?)* ***R*** *comes about*".
This is exactely the way followed in constructing the theory which simultaneously describes the***U***-and the ***R***-processes in quantum field theory with exactly the same accuracy.Here is,however, an additional aspect: In this approach ***R*** comes about not only for large- scale systems, but also for single quantum particles, thus enabling us to get a glimpse of the neutral kaon branching process and to solve the Schroedinger cat's puzzle, too. The first and basic idea came to us from [6] and a first derivation has been given in [1,2].

Penrose continues: "*It appears that people often think of the precision of quantum theory as lying in its dynamical equations, namely* ***U****. But* ***R*** *itself is also very precise in its prediction of probabilities, and unless it can be understood, how it comes about ,one does not have a satisfactory theory*".
In the second statement by Penrose it seems to us that the freedom is contained that ***R*** be or not be a consequence of the same dynamics. It is shown that theory gives both***U*** and ***R*** with exactly the same precision, and it is demonstrate that ***U*** and ***R*** come about by means of quantizing the field action-integral.

V.2 Experience and expectation

After the above due clarifications one is ready to "play dice" and answer the questions entailed by the problem posed at the beginning of this section: In studying the game, one may do some small calculation and figure out what one has to expect after throwing a dice.

The probability is 1/6 for getting any number from 1 to 6:

Calculated final state of the dice =

$$F = 1/6 \times (\text{get } 1) + 1/6 \times (\text{get } 2) + \ldots\ 1/6 \times (\text{get } 6). \qquad (11)$$

This is,of course,the result of a *calculation* of what is foreseen. There is no relationship whatsoever - causal or acausal - with the a future decision for doing or not doing the experiment. It is an ***empirical*** statistical fact independent of whether one plays or does not play dice in future.The result of the *calculation* (11) will not change after throwing the dice.The equation remains unaffected, if the dice shows,e.g., 5 or anything else.

After having played dice one knows the *fact* and one may represent it, e.g., by *Exp*(erimental)*Res*(ults) =

$$F_{\text{exp.}} = 1 \times \text{(got 5), and } 0 \times \text{(got all others).} \qquad (12)$$

But equation (11) remains unaltered. «Calculations» and «fact» are related only in observers' brains.

F in (11) is a theory-devised construct for predictions based on empirical data, representing the *possibilities* for many different (in this case 6) outcomes of dicing.

Equation (12) is of a different character. It is constructed to represent *a posteriori one single fact*:The *outcome of one single experiment,*and there can be no question about any reduction.

Next, one may make more perfect the theory of playing dice and construct an operator,***D***, describing the dice playing.One wants ***D*** to describe the dice-throwing.This will be done by applyng ***D*** on F. The result of this application will, if the theory is a good one, be $F_{\text{exp.}}$. It will induce the *reduction* on the paper, not in Nature.

If F and ***D*** represent ***exactly*** the system and the action on it respectively, then

$$\boldsymbol{D}\,\mathrm{F} = 1 \times \text{(got 5), and } 0 \times \text{(got all others),} \qquad (13)$$
$$= F_{\text{exp.}}$$

and ***D*** describes exactly the way of taking and throwing the dice (the dynamics) in the particular experiment above. It has nothing to do with a statistical theory (Einstein).

Let us see a little more precisely what means the expression:"***in the particular experiment***". It means:

i) *A definite motion of the hand of the particular experimentalist,implemented through a definite preparation and function of his hand-muscle system.*

ii)*Adefinite motion of his arm,implemented through a definite preparation and function of the arm-muscle system.*

iii)*Adefinite electrical conductance or polarization and function of the neural synapses system etc. leading from the brain to the fingers of his hand.*

iv) *A certain preparation and function of his brain,conscious to a certain degree of the programme to be carried out.This degree of consciousness may differ from one experimentalist to an other, and to an experimentalist in different experiments.*

v) *Acertain interaction between his «will»and his brain in order that the latter prepares itself and acts.*

These five steps of preparation are subject to large uncertainties, both macroscopic and quantum mechanical. The magnitudes of the uncertainties increase with increasing index value in the above enumeration scheme from i) to v).
Moreover,what is virtually fully undefined is the description in physical terms of the interaction between the «will» and the brain.

Hence,the construction of the operator ***D*** for experiments of the above type is not an easy task for today's Science and Technology. The difficulty is localized in the lack of knowledge in the quantum description of the individual human functions.
However, in most nuclear physics experiments participation of human body' s functions at the realization of experiment's crucial parts is to a well-defined degree excluded. Also, the human brain is involved only in the preparation of the experiment, in the analysis and in the interpretation of the *ExpRes*. Hence, the construction of the operator ***D*** in nuclear experiments is in general feasible and easier.
Similar is the situation in quantum theory. Long experience and deep insight have shown two series of facts:

i) If one constructs a certain function, $\mathcal{L}$, appropriate to the problem at hand and applies a variational principle, one derives an equation (Schroedinger), containing some operators $\{\boldsymbol{D}\}$, which corresponds to the problem.
ii) The actions of $\{\boldsymbol{D}\}$ on a certain function F=f(Ψ) (Ψ is a wave function) describe satisfactorily the *ExpRes*,and the construction of the function , $\mathcal{L}$, is correct.

Hence, if the theory is correct, then one must have:

$$\boldsymbol{D}\, f(\Psi) = ExpRes.$$

Some authors believe that the construction of ***D*** is impossible in the framework of the theory of Schroedinger's equation in such a way that the above equation is not true in the sense of (13) and ***R*** must come from extraneous agents. One shall try to examine the actual situation in the framework of the present chrono - topology. One shall try first to clarify the situation through the following definitions.

V.3 Nature is not divisible in classical and quantal

Definition VIII.1

Every experiment in systems ranging from atomic to sub - nuclear is divided into two parts:

i) The experiment proper which involves one fundamental physical ***interaction,*** *relies on the laws of quantum physics and characterizes* ***D*** *(****D****-process).*

ii) The process of making a quantum interaction ***visible*** *may rely either on quantum laws or on laws of classical physics or on both and is not characteristic of* ***D*** *(non* ***D****-process).*

iii) There are many ways ,$X \in \{W_i, P_i | i = 1,2,...\}$ *,for implementing an ExpRes appropriate either to wave properties,* W_i*,or to particle properties,* P_i*, but not simultaneously to both .*

iv) Proposition ii) can be implemented in any one of the possible ways $X \in \{W_i, P_i | i = 1,2,...\}$ *,and, hence, Xis not an uniquely chacteristic part of the experiment proper.*

v) The elements of the set $\{ExpRes(X)\}$, $\forall X \in \{W_i, P_i | i = 1,2,..\}$, *are equivalent:*

$$ExpRes(X) \Leftrightarrow ExpRes(Y), \ \forall (X,Y) \in \{W_i, P_i | i = 1,2,...\}. \qquad (14)$$

Remark 4

*According to **Definition VIII.1** an experiment in quantum physics consists of a fundamental interaction between two given quantum entities, on the one hand a structured or an elementary particle, and on the other hand, a measuring apparatus, whose **specificallyactive part** may be another structured or annother elementary particle or a field.*

Remark 5

The process of making the *ExpRes* macroscopically observable is a separate step,exterior to the quantum measurement.

Remark 6

The view that in every quantum physics experiment one has the **interaction of a quantum system** with a **classical apparatus** (black box approach) does not correspond to reality according to the present work premises. Because the method used for the indication of the result of a fundamental interaction is not essential to the quantum experiment.As a rule, the *ExpRes* is obtained by means of photomultipliers,scintillators,Wilson chambers, Geiger-Mueller detectors, recoil detectors, spark detectors and other well-known elementary particle detectors.The way to magnify a quantum interaction does not play an essential part in the interpretation ***per se*** and to the construction of the operator ***D***, as (14) makes clear.

Having the above clarifications in mind one can see that in constructing the operator, ***D***, implementing the measuring process in a quantum experiment, one does not need any input extraneous to the interacting quantum system. One thing,which,however, is not extraneous to the quantum interacting system, is the preparation of the experiment. One must, further, specify, what one understands under «preparation of the experiment».

Definition VIII.2

The preparation of a quantum experiment consists of two processes:

*a) The preparation of the state of the elementary or the structured particle determined to interact with the **active part** of the measuring apparatus.*

*b) Preparation of the **active part** of the measuring apparatus and of its state to measure either a particle property,* P_i *,or a wave property,* W_i .

Definition VIII.3

i) A quantum measurement is the experimental determination of one or more quantum transitions in the prepared system. The transition may consist in the change(s) of some observable(s)during a fundamental interaction in the prepared quantum system and the active part proper of the measuring apparatus.

ii) The preparation of an experiment influences the system to be measured in such a way that it increases or diminishes the probabilities for one or a few of the possible outcomes, constituting the ExpRes to be determined. These ExpRes are associated by means of the preparation with higher probabilities relative to all other possible outcomes.

Remark 7

Accordingly,one understands that the critical part of a quantum experiment is *an interaction between two particles, or between a particle and a field, or between two fields causing the evolution of the system whose some observables are to be determined within its corresponding IPN either in the interacting system rest frame of reference or in observer's system of reference.*

V.4 Schroedinger's equation produces R

Proposition 2

The reduction of the state vector describing a quantum measurement is effected by the evolution operator $\boldsymbol{D}(\delta(\tau))$ with the interaction Hamiltonian, $H(t)$, appropriate to the preparation of the experiment for $t \in \tau$. $\boldsymbol{D}(\delta(\tau))$ reduces the probability amplitudes $\{C_n(0)\}$ of all components of the state vector

$$\Psi(x) = \sum_n C_n(0)u_n(x)$$

representing the system under measurement, except the ones

$$\{C_\alpha(0)|\alpha = 1,2\ldots K < \infty\}$$

corresponding to the observables $\{O_\alpha|\alpha = 1,2\ldots K < \infty\}$ to be obtained in the ExpRes.

Proof

The $\boldsymbol{D}(\delta(\tau))$ can be taken equal either to $\mathcal{U}_{nmp}(\delta(\tau))$ or $\mathcal{U}_u(\delta(\tau))$ depending on the case. In the present case one puts : $\boldsymbol{D}(\delta(\tau)) = \mathcal{U}_{nmp}(\delta(\tau))$.

$$\mathcal{U}_{nmp}(\delta(\tau)) = \exp\Big\langle\ [(i\hbar)^{-1}\int_{\overline{M}_\kappa^4} d^4x\,\mathcal{H}(\varphi(x,t),\partial\varphi(x,t)) + i\Lambda(j,\sigma)]\times$$

$$[\cos[\Lambda(j,\sigma)] - i\sin[\Lambda(j,\sigma)]]\ \Big\rangle, \tag{15}$$

before quantization.

The expression for the experiment comes about through the selection of the appropriate quantum numbers in $\Lambda(j(n),\sigma)$ following the quantization of the field action-integral (15).

The kind of quantization to be applied becomes clear from the expectation to have a non - measure - preserving evolution or a unitary evolution. I.e., expect to measure substantial changes in the relative probability measures of the components characterizing the system before and after the measurement with respect to the remaining components.

Carrying out the multiplication of the quantities in the brakets [...] × [...] of the exponent in (15) it is seen that the above requirement is fulfilled according to (7.13 of ref. [11]), if one puts

$$\Lambda(n,\sigma) = \pi(2n + 1/2), \sigma = 1\,. \tag{16}$$

From (16) it follows after application of (15) on the state vector that

$$\mathcal{U}_{nmp}(\delta(\tau))\Psi(x) = \exp\Big\langle\ [\frac{\mp 1}{\hbar}\int_{\overline{M}_\kappa^4} d^4x\,\mathcal{H}(\varphi(x,t),\partial\varphi(x,t)) \mp\Lambda(j(n),\sigma)]\ \Big\rangle\,\Psi(x)$$

$$= \sum_{n=1}^{\infty} \exp\langle\ [\frac{\mp 1}{\hbar} \int_{\overline{M}_\kappa^4} d^4x\, \mathcal{H}(\varphi(x,t), \partial\varphi(x,t)) \mp \Lambda(j(n),\sigma)]\ \rangle\, C_n(0) u_n(x)$$

$$= \sum_{n=1}^{m} \exp\left\langle [-\hbar^{-1} \int_{\overline{M}_\kappa^4} d^4x\mathcal{H}(\varphi(x,t), \partial\varphi(x,t)) - (j(n)+1/2)] \right\rangle C_n(0) u_n(x)$$

$$+ \sum_{\alpha=1+m}^{m+K} \exp\left\langle [+\hbar^{-1} \int_{\overline{M}_\kappa^4} d^4x\mathcal{H}(\varphi(x,t), \partial\varphi(x,t)) + (\alpha(n)+1/2)] \right\rangle C_\alpha(0) u_\alpha(x)$$

$$+ \sum_{n=1+m+K}^{\infty} \exp\left\langle [-\hbar^{-1} \int_{\overline{M}_\kappa^4} d^4x\mathcal{H}(\varphi(x,t), \partial\varphi(x,t)) - (j(n)+1/2)] \right\rangle C_n(0) u_n(x).$$

By appropriately choosing the respective action-integral values, i.e., $\{j(n)\}$ in each category of states in the sum, one obtains that only the intermediate sum survives.The corresponding exponents are the sums of two positive numbers. The first and the third sums above become as small as one likes by taking the differences in the respective exponents sufficiently small in comparison with the smallest term in the sum , as implies the preparation of the experiment $\alpha \in [1+m, n+K]$.

$$\mathcal{U}_{nmp}(\delta(\tau))\Psi(x)$$

$$\cong \sum_{\alpha=1+m}^{K} \exp\left\langle [\hbar^{-1} \int_{\overline{M}_\kappa^4} d^4x\mathcal{H}(\varphi(x,t), \partial\varphi(x,t)) + (\alpha(n)+1/2)] \right\rangle C_\alpha(0) u_\alpha(x). \quad (17)$$

If the set of the orthonormal functions $\{u_n(x)\}$ are eigefunctions of the energy operator, then (17) can be simplified in the form

$$\mathcal{U}_{nmp}(\delta(\tau))\Psi(x)$$

$$= \sum_{\alpha=1+m}^{K} \exp\langle [\hbar^{-1} E_\alpha \delta(\tau) + (\alpha(n)+1/2)] \rangle C_\alpha(0) u_\alpha(x)$$

$$= \sum_{\alpha=1+m}^{K} C_\alpha(\delta(\tau)) u_\alpha(x),$$

where

$$C_\alpha(\delta(\tau)) = \exp\langle [\hbar^{-1} E_\alpha \delta(\tau) + (\alpha(n)+1/2)] \rangle C_\alpha(0).$$

Obviously, the probability coefficients for the surviving states is much larger than the rest of them

$$|C_\alpha(\delta(\tau))|^2 >> |C_n(\delta(\tau))|^2, \forall \alpha \in [1,K], \forall n \in Z^+ \setminus [1,K], \quad (18)$$

and the proof ***Proposition 2*** is complete.

Remark 8

This is the expected result describing the preparation of the experiment and implying the reduction, ***R****, of the wave function after the experiment. It is seen that* ***R*** *is an integral part of quantum dynamics, and it does not need the presence of any extraneous agents. The numbers $\alpha(n)$, $j(n)$ and K depend on the preparation and the kind of interaction in the experiment. $\{\alpha(n)\}$ may be large, $\{j(n)\}$ are correspondingly of the orders of $\{E_n\}$. K is in most experiments equal to 1.*

Remark 9

The novum in the above proof is:

i) It is seen that R does not imply necessarily reduction to one single state, but to any finite number, K, of final states.

ii) The reduced states are not fully extinguished! They simply become of a very small probability.

iii) The result ii) above steresses the ***statistical appearence*** *of quantum theory which is traced back to the* ***chrono-topology.***

VI Conclusions

The chrono-topology implies that the physical fields become generalized and infinitely divisible random fields. In particular, the Hamiltonian and the Lagrangian densities acquire this property. This property has been used by R.P. Feynman in the derivation of his famous path integral. Based on the chrono-topology and by quantizing the action integral we obtained the solution of the measurement problem. The reduction of the state vector consists not in the vanishing of all components of the state vector except one, but rather in the extiction of all but one or a finite number of components. This underlines the statistical look of quantum theory of nuclear reactions.

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