MANY TIME INTERPRETATION OF THE QUANTUM MEASUREMENT PROCESS

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Abstract : This is a short version of the, so-called, Many Time Interpretation (MTI) of the quantum measurement process. MTI does not involve any new hypothesis, but rather represents a suggestion for "re-reading" of the positive statements of the existing measurement theories. Quite shortly : Instead of the "indeterminism" with regard to the unique Time, in nonrelativistic quantum measurement theory MTI establishes "determinism", but with regard to the sets of the different (local) Times.

The very basis of MTI is a semi-epistemological analysis of the concept of physical time (Time) in classical, nonrelativistic physics. Particularly, we offer an operational definition of Time, which "establishes" Time as an "ordering principle" of the classical-physics world.

When applied to the analysis of the quantum measurement process, the above mentioned definition strongly suggests the main interpretational rule of MTI: each particular (single) "object" in due course of quantum measurement represents an object of stochastic change (choice) of Time. Thus each particular "object" experiences its own, local Time, which is as objective (real) for the actual "object", as the "macroscopic" Time is objective in classical physics.

However, the analysis concerning the "object" alone appears somewhat naive. The full analysis refers to the composite systems, "object + apparatus (O+A)", and "object + apparatus + environment (O+A + E)". This way one obtains justification of the analysis concerning the "object" alone, however implying some nontrivial physical notions. Particularly, the given axiomatization of MTI leads to : (i) Recognizing the amplification process as the fundamental "part" of the measurement process, (ii) Nonvalidity of the Schrodinger equation concerning the "whole", O+A+E, which makes the "state reduction process" unnecessary and unphysical, (iii) Natural deducibility of the macroscopic irreversibility, and (iv) Nonequivalence of MTI with any existing measurement theory, or interpretation. Thus, within MTI, the measurement problem reduces basically onto the search for quantum effect, which would allow for the local, stochastic change of Time.

Extended Abstract : This is a short version of the, so-called, Many Time Interpretation (MTI) of the quantum measurement process. MTI involves no new hypothesis, but rather represents a new "re-reading" of the positive statements of the existing quantum measurement theories. Quite shortly : MTI relies upon the semi-epistemological analysis of the concept of physical time (Time, or Time axis) in classical, nonrelativistic physics. When applied to the quantum measurement situations, this analysis suggests abandoning the concept of unique (universal) Time and, in a "long run" leading to a simple interpretation of the measurement process, naturally implying the macroscopic irreversibility.

We give a ("operational") physical definition of Time in classical, nonrelativistic physics. In more subtle analysis, our definition of Time bears significant similarities with
the Aristotle-Leibnitz-Mach approach to the same issue - sometimes referred to as the "relational theory of time". Our definition of Time establishes this concept as a sort of the "ordering principle" of the classical-physics world. Actually, the definition appears physically equivalent with the next set of the basic physical concepts: (a) time instants and intervals, (b) existence of the physical laws, and (c) validity of the conservation laws.

In analysing the quantum measurement process we depart from the widely used ensemble-interpretation. Actually, we refer to the single "object" which in due course of the quantum measurement "meets" (with some probability $W_i$) a transitional "channel" $\Psi \rightarrow \Psi_i$. When applied the above mentioned definition of Time onto the "channels", one reaches the main interpretational rule of MTI: in due course of the quantum measurement process, each particular "object" becomes an object of stochastic change of Time axis. For an "object", the actual (local) Time should be considered as objective (real) as the "macroscopic" Time is objective in classical physics.

When expressed in terms of the "macroscopic" Time, MTI reduces onto the stochastic choice of the quantum-mechanical laws (still, of unknown form), each law governing the different "channel", e.g., the i-th "channel", $\Psi \rightarrow \Psi_i$. This is usually referred to as "indeterminism". However, MTI is not equivalent with this - its somewhat naive reduction with respect to the "macroscopic" Time.

Still, the analysis concerning the composite systems, "object + apparatus (O+A)", and the "object + apparatus + environment (O+A+E)", is the full - and unavoidable - quantum-mechanical analysis. By the use of the fact that the quantum measurement implies breaking of some of the "conservation laws" concerning the system O+A, the role of the environment appears both, necessary and essential in this context. Among else, the application of the main interpretational rule of MTI onto O+A+E implies nonvalidity of the Schrodinger equation concerning O+A+E, and therefore the process of the "state reduction" appears both, unnecessary and unphysical.

Besides, in an axiomatic form, MTI nontrivially extends and enreaches our notions concerning the "border territory" between the "microscopic" and "macroscopic" parts of the physical world. Particularly, one meets amplification process as fundamental quantum process, and obtains deducibility of the macroscopic irreversibility.

Therefore one may say: MTI suggests abandoning the concept of universal physical time even in nonrelativistic physics, while ascribing the "determinism" to each local Time axis, which appears in due course of quantum measurement. MTI allows for overcoming the problem of "state reduction", and in natural way provides deducibility of the macroscopic irreversibility. Finally, the quantum measurement problem appears reduced onto the search for a quantum effect, which would allow for the local, stochastic change of Time.
BARE ESSENTIALS OF MTI

Quick reader should refer to the Abstracts, Section 18, likewise to the Outlook and Conclusion, given on the end of this text. Below, we give the bare essentials of MTI, and where they can be found in the text. Especially, one may refer to the Sections 20 and 21.

1. MTI proposes nonuniqueness (nonuniversality) of the physical ("macroscopic") time in quantum, nonrelativistic physics. (Cf. Sections 8-10, 12, 13, 17)

2. In due course of the quantum measurement process, each singular (particular) "object" experiences its own (local) Time (Time axis). The choice of Time axis is stochastic. (Cf. the Sections given above)

3. The point "2." above is justified by considering the composite systems, "object + apparatus", and "object + apparatus + environment". (Cf. Sections: 13-15, 17)

4. When reduced onto the terms which refer to the "macroscopic" Time, MTI reproduces the results which are usually considered as (quantum) "indeterminism". Still, the inverse is not correct (i.e., this reduction of MTI does not necessarily imply (lead) to MTI), and thus can not be considered equivalent with MTI itself.

5. MTI implies nonvalidity of the Schrodinger (unitary) evolution concerning the "whole", "object + apparatus + environment". This directly imples the "state reduction process" unnecessary and unphysical. (Cf. Sections: 14, 16)

6. Within an axiomatization, MTI offers a new, richer physical picture. Among else, one obtains possibility of simple and natural deducing of the macroscopic irreversibility. (Cf. Sections 20)

Instead of the "indeterminism" with regard to the standard, "macroscopic" Time, in the quantum measurement theory MTI establishes "determinism", but with regard to the different possible (local) Times.
1. INTRODUCTION

This is a short version of the, so-called, Many Time Interpretation (MTI) of the quantum measurement process. MTI does not involve any new hypothesis, but rather relies upon the positive (i.e., interpretation free) elements of the existing measurement theories.

Here we give almost just the bare essentials, and the interesting reader may refer to Dugić 1998 for more details.

The subject will be presented ”iteratively”. For the quick reader it might be convenient to refer basically to the Sections 20-23.

Finally, we give the particular definitions of the concepts of determinism and causality, to be used below.

By determinism we assume existence of a definite physical state of a system, completely independent on an act of measurement (observation).

By causality we assume that, given a physical state of a system in an instant \( t_0 \), the state of the system in each later instant \( t \) is known with certainty.

2. DEFINITION OF TIME IN CLASSICAL PHYSICS

In this Section we give an operational physical definition of Time in classical, nonrelativistic physics.

This will bring us to somewhat specific notion on the concept of the ”macroscopic” Time as an ”ordering principle” of the classical-physics world.

2.1 Puzzling over Time

Usually, Time appears in physics as a metaphysical concept, which is postulated, rather than defined. Furthermore, it is sometimes argued that the concept of Time, as the physicists use it, can not be properly defined.

In our opinion, this point of view is not correct, or at least not the only one considerable. For, from the operational point of view, the ”flow of (metaphysical) Time” in classical physics is represented (”interpreted”) by the dynamics (”motion”) of the ”ideal clock” (cf. Appendix I). Furthermore, from an operational point of view, one may hardly ever say more about the physical Time, then it is directly presented by the dynamics of the ”ideal clock”. And this is the physical basis which justifies our attempt in approaching a proper definition of the ”macroscopic” Time.

2.2 The ”primitives” of our approach

The elementary observation in physics defines what we call dynamics:

\[
D = \{A, B, C, \ldots\},
\]

where \( A, B, C, \ldots \) represent the ”points” in the corresponding physical state space, \( P \), of the observed object. Usually, the dynamics (1) is presented by some kind of ”record”
("memory"), which clearly involves ordering of the elements, \( A, B, C \ldots \). And (cf. Appendix II) it is just our psychology which refers to the "ordering" with respect to the "flow of Time" - thus implying the circular reasoning. However (cf. Appendix II), there is no circularity in our reasoning; in other words: we think that the observation does not require an "instantaneous" interpretation of the observation.

The concept of dynamics \( D \) is a "primitive" of our approach and, by definition, does not call for the more elementary ("primitive") concepts - of course, except the concept of state space, \( P \).

As another "primitive" of our approach appears the concept of "Causality", \( C \). Note, it is not the causality defined in Section 1. Actually, we postulate (cf. Appendix III for motivations) that, given each two neighbourghing "points", e.g., \( A \) and \( B \) of the dynamics \( D \), that there is unique continuous "trajectory" in \( P \), connecting the two "points". As it was emphasized in Appendix III, the "Causality" is physically equivalent with the concepts of physical law(s), i.e., with the concepts of determinism and causality defined in Section 1 above.

**2.3 The concept of physical dynamics**

From the two "primitives" of our approach, we deduce the main concept of this Section: the concept of physical dynamics, defined by:

\[
D_p = \{ A \rightarrow_c B \}. \tag{2}
\]

One should note that (2) is not mathematical, but physical expression, which should be understood: each change of physical state \( A \), to state \( B \), is governed by the "Casuality" - which refers to existence of unique and continuous "trajectory" governing the transition. And this applies generally: to each physical system ("object") in classical physics, to each particular (neighbourghing) states \( A \) and \( B \), and irrespective of physical nature of the system.

**2.4 Our definition of Time**

We give the operational physical definition of Time:

\[
D_p = \{ A \rightarrow_c B \} : T_M = (t_A^{(M)}, t_B^{(M)}). \tag{3}
\]

By \( T_M \) we denote the "macroscopic" Time, while the pair \( (t_A^{(M)}, t_B^{(M)}) \) gives the "instants" corresponding to the states \( A \) and \( B \), respectively. It is not (cf. Appendix IV) important if this pair is (non)unique. However, what is - by definition - important is that: for the particular instant \( t_A^{(M)} \), the instant \( t_B^{(M)} \) is known with certainty.

**2.5 Discussion**

We do not claim that "macroscopic" Time, \( T_M \), is not "real" ("objective"). For, simply, it is not objective of our considerations! Our objective is to obtain a physically sound definition of Time, starting from the purely physical data. Therefore we refer to
as to the *operational physical definition of Time*. This definition establishes physical *existence of Time*, rather than it should be considered complete.

However, our approach - being concerned with the phenomenological data - bears significant similarity with the *Aristotle-Leibnitz-Mach* approach to the same issue. Sometimes, this approach is called ”relational” theory of time (cf. Withrow 1979). Now, due to some shortcomings of this theory, one may wonder about the shortcomings in our definition of Time.

However, we do not see this appealing. Our definition of Time can be considered independently on the ”relational” theory of time, on the footing established above, and in Appendices I-IV. Still, in some more sophisticated analyses, this might come to scope. Yet, we think that this can be considered to be of the secondary importance for our considerations - as we hope to become clear below.

Finally, the concept of physical dynamics - in our approach underlying the concept of Time (although, usually (cf. Appendix IV) it is just the inverse) - ”brings” into the concept of Time the concept of ”Causality”. Thus one meets the concept of Time, *as defined above*, as an ordering principle in the classical-physics world; existence of the ”order” follows from postulating ”Causality”, which is physically equivalent with existence of the physical laws, i.e. with the concepts of determinism and causality (as defined in Section 1).

### 3. SCHRODINGER EQUATION

The Schrodinger equation is the law of isolated quantum systems, and apparently admits for introducing the concept of *quantum dynamics*, in full analogy with (2):

$$D_Q = \{ \Psi_i \xrightarrow{C} \Psi_f \}$$

where $\Psi_i$ is the initial state, while $\Psi_f$ is the final state, determined by an instant $t$ of the ”macroscopic” Time, $T_M$: $\Psi_f \equiv \Psi_t$.

Certainly, contrary to $D_p$ defined by (2), the quantum dynamics $D_Q$ does not appear as a result of physical observation. Still, $D_Q$ bears all the basic physical features of $D_p$, and therefore can be considered in physically essentially the same way, i.e., considered as a ”primitive” of our considerations. Particularly, the ”Causality”, $C$, establishes (postulates) existence of the unique continuous ”trajectory” in the Hilbert state space of the system, and is physically equivalent with the Schrodinger equation - $\hat{U}(t)\Psi_i = \Psi_t \equiv \Psi_f$.

Certainly, the concepts of determinism and causality (cf. Section 1), now apply to the elements of the Hilbert space - as the physical state space of the system.

Now one can note : the quantum dynamics $D_Q$ sublimes the basics of QM of isolated systems in the manner in which the physical dynamics $D_p$ sublimes the basics of classical (nonrelativistic) physics. Since both dynamics refer to the ”macroscopic” Time, $T_M$, one may equally state :

$$D_Q = \{ \Psi_i \xrightarrow{C} \Psi_f \} : T_M = (t_i^{(M)}, t_f^{(M)})$$

in full - certainly, physical - analogy with (3).

### 4. QUANTUM STATE OF A SINGLE QUANTUM SYSTEM
The usual, ensemble-interpretation of QM treats the ("pure") quantum state \( \Psi \) merely as a source of informations, which could be provided by a proper quantum measurement procedure.

An ensemble is defined as composed of the individual "elements" - i.e., of the single quantum systems. The quantum state \( \Psi \) of an ensemble is assumed to be defined (determined) by a proper "preparation" procedure. Still, it is widely, although primarily implicitly, assumed that each single system, which is an element of an ensemble in "pure" state \( \Psi \), is also in this, "pure" state \( \Psi \). [This can be further elaborated, but we shall omit it here.]

Bearing this statement in mind, we conclude that the dynamics (4), likewise the concepts of determinism and causality (cf. Section 1), appear applicable to each single system "described" by the quantum dynamics (4).

5. THE GENERAL QUANTUM MEASUREMENT SCHEME CONCERNING THE QUANTUM "OBJECT"

The next scheme represents a proper generalization of the real quantum-measurement situations:

\[
\Psi \rightarrow \Psi_1, \quad W_1
\]

or

\[
\Psi \rightarrow \Psi_2, \quad W_2
\]

or ...

\[
\Psi \rightarrow \Psi_n, \quad W_n
\]

etc, where \( \Psi \) is the initial state, while \( \Psi_i \)s represent the different final states ("outcomes"), while the probabilities \( W_i \):

\[
\sum_i W_i = 1.
\]

The usual, ensemble-interpretation states that (S1) can be written as:

\[
\Psi \rightarrow \hat{\rho} = \sum_i W_i \vert \Psi_i \rangle \langle \Psi_i |,
\]

i.e., that the ensemble, initially in the "pure" state \( \Psi \), survives non-Schrodinger transition to the "mixed" state \( \hat{\rho} \).

It is important to note that, according to the Section 4, the ensemble-interpretation states that the same transition, (7), also refers to each single object of quantum measurement, i.e., that each single "object" survives the same transition from the initial "pure" \( \Psi \), to the final "mixed" state \( \hat{\rho} \).

6. A CLUE OF MTI 1
Here we propose a new "re-reading" of the scheme (S1). Our proposal should not be understood to claim that the usual, the ensemble-interpretation, is not correct, but just that it is not the only one possible.

What we suggest is to distinguish the different transitional "channels" in (S1) : the first "channel" refers to the transition $\Psi \rightarrow \Psi_1$, the second "channel" to the transition $\Psi \rightarrow \Psi_2$, etc.

Now, and this is the point to be strongly emphasized, as regards the single "objects", one may note that: each single "object" has a choice between the different transitional "channels". This choice is governed by the corresponding probability distribution, $\{W_i\}$, which must be tested on an ensemble. I.e., the choice of the "channel" should be considered to be stochastic.

Therefore, we propose to consider the transitional "channels", e.g., the i-th one:
\[ \Psi \rightarrow \Psi_i, \] 

as the real physical process for the actual single "object". Therefore, in this context, the physical place of the probabilities $W_i$ is yet to be determined.

7. COMMENTARY

Needless to say, the transition due to the i-th "channel" appears as a quantum analogue of the classical dynamics (1) which defines the dynamics of the quantum measurement process:
\[ D_i = \{\Psi, \Psi_i\}. \] 

Besides, after the measurement has ceased (relative to the "macroscopic" Time $T_M$), the evolution of the object is governed by the Schrodinger law.

Here we make an ansatz concerning the "channels": actually, we assume existence of the physical law which should govern the transition due to the given "channel":
\[ \hat{U}_i \Psi = c_i \Psi_i, \] 

where $c_i$ is a "complex number", and which is a consequence of, in general, that the "evolution operator" $\hat{U}_i$ needs not to be unitary. Certainly, there is the time dependence $\hat{U}_i(t^M)$, which is for the simplicity omitted above.

The presumption concerning existence of $\hat{U}_i$ follows from our main assumption: that the transitional "channels" refer to the real physical processes. Then, certainly, there must exist the law Eq. (10) (and also its the differential form). [It is obvious that we just state existence, but not the mathematical form of the law (10).]

In the usual ensemble-interpretation the existence of $\hat{U}_i$s would be interpreted as a formal expression of "indeterminism". However, we offer a new point of view, which is the basis of MTI.

8. A CLUE OF MTI 2
The very existence of $\hat{U}_i$s admits for introducing the concept of *quantum dynamics* in the context of the quantum measurement process, by:

$$D_{Qi} = \{ \Psi \xrightarrow{C_i} \Psi_i \},$$

and which should be read (understood) in full analogy with (3) and (4), bearing in mind that the index “$i$” in $C_i$ refers to the i-th operator $\hat{U}_i$ - cf. (10). [Certainly, we assume that the ”Causality” $C_i$ refers to unique and continuous ”trajectory” in the Hilbert space, but this is not substantial assumption here - cf. Appendix V.]

Note that all the physical dynamics, (3), (4) and the stochastic one, (11), have the same physical contents : they all refer to the single ”objects”, bearing determinism and causality (with regard to the Hilbert state-space). This is what gives us right to make another, substantial step in our interpretation, i.e., to define the different Time axes:

$$D_{Qi} = \{ \Psi \xrightarrow{C_i} \Psi_i \} : T_i = (t^{(i)}, t^{(i)}_i),$$

bearing some redundancy in the indices.

The expression (12) is the very form of the main interpretational rule of MTI : In due course of the measurement process, each single ”object” becomes an object of stochastic - with probability $W_i$ - change of Time, i.e., of the choice of the Time axis, $T_i$. Each Time axis $T_i$ is as real (objective) for the actual ”object”, as the ”macroscopic” Time axis, $T_M$, is real in the classical physics. [Therefore, the physical ”origin” of the probabilities $W_i$ is yet to be determined, by determining an effect which should provide the stochastic change of Time.]

9. A CLUE OF MTI 3

We propose the Time axes $\{T_i\}$ to be considered seriously. That is, that the ”macroscopic” Time, $T_M$, should be considered just as an example of physical Time. And : we have abandoned the concept of unique (universal) Time even in nonrelativistic physics, but have ascribed the determinism and causality to each Time axis. In so far as we can see, this is in no contradiction with the present state of art in quantum measurement theories.

Intuitively, MTI suggests introducing the sudden, stochastic choice of local physical worlds, each of which is established and ”ordered” in the same way (qualitatively), as is the case with the classical (”macroscopic”) physical world, which is ”ordered” by $T_M$. Certainly, the macroscopic objects are the objects of the macroscopic Time, and therefore of the macroscopic physics laws. Similarly, an ”object” experieces its own local Time axis (world), which defines its ”own” quantum laws, which can be thought about (cf. Section 11), but not directly experied by the macroscopic bodies. This further means that the macroscopic clocks can only and exclusively measure the ”macroscopic” Time. What then one can admit as a ”clock” for the ”microscopic” Times? The answer is : the dynamics of the ”objects”, $D_{Qi}$, itself. I.e., the ”object” itself represents (for definition cf. Appendix 1) an ideal clock for the corresponding Time axis. We now hope to be clear that what we should do at this point, is to make some connections between the instants and intervals of the ”macroscopic”, and the local (”microscopic”) Times.
10. ONE TIME OR MANY TIMES?

One may wonder if the interpretation in terms of the different Time axes is really necessary. There are a few answers with respect to the different, implicit aspects to this dilemma.

First, this interpretation is not necessary - otherwise, the standard one would never come to scope. What we claim is that MTI is not forbidden.

Second, we use the term Time as physically essentially equivalent with the concept of physical/quantum dynamics. [This is justified by the definition of Time in Section 2, and the fact that all the basic features of the physical dynamics, (2), appear in (4) and (11) - as it is distinguished in Section 8]. However, if one would claim the opposite - i.e., that (5) and (12) can not be considered as a recognition of the different Times - this would mean that, physically, we know much more about Time than it is stated by the definition (3); for our point of view see Appendix I.

Finally, one may note that the operators $\hat{U}_i$ (cf. Section 7) appear physically sufficient (e.g., as a formal expressions of the standard "indeterminism"), therefore offering no new contents. We note that MTI reduces itself onto this picture, but with regard to the one and unique (universal), "macroscopic" Time; that is, MTI appears reducible onto the set of the given operators, $\hat{U}_i$, of Section 7. However, and this is the point to be emphasized, this reduction of MTI does not appear equivalent with MTI itself. And this is going to be proved below (cf. Section 12).

Therefore, it is admissible to deal with nonunique Time in the context of the quantum measurement theory.
11. A CLUE OF MTI 4: SOME FORMAL EXPRESSIONS

If each Time axis, $T_i$, should be considered physically equal with the "macroscopic" Time, $T_M$, then everything that can be physically stated in terms of $T_M$, should be expressible in terms of the instants (intervals) of each local Time, $T_i$. Instead of being exhaustive in this respect, let us refer to the operators $\hat{U}_i$ of Section 7.

According to the rule of Section 8, one should refer to an operator $\hat{U}^{(i)}$, which should be seen as the "evolution operator" concerning the Time axis $T_i$ - i.e., concerning the $i$-the "Causality", $C_i$. Certainly, this operator defines the quantum law, which refers to the $i$-th "channel", and can be written as:

$$\hat{U}^{(i)} \equiv \hat{U}^{(i)}(t^{(i)}). (12)$$

When compared to Eq. (10), the expression (12) leads to equality:

$$\hat{U}_i(t^{(M)}) = \hat{U}^{(i)}(t^{(i)}), (13)$$

which implies (as it is required in Section 10) connectability of the instants and intervals of the Time axes, and particularly:

$$dt^{(i)} = g_i(t^{(M)})dt^{(M)} , (14)$$

with obvious meaning, while generally: $g_i(t^{(M)}) \neq 1$.

However, it is interesting to note that (14) has an important, direct consequence. Actually, if one may write:

$$\frac{d\hat{A}}{dt^{(M)}} = 0, (15)$$

then (14) directly implies:

$$\frac{d\hat{A}}{dt^{(i)}} = 0. (16)$$

Therefore, the requirement of the full physical equality of the Time axes is fulfilled: each Time axis has its own "instants" and "intervals", defining the corresponding quantum law for the actual "object", and allowing for the general validity of the conservation laws.

[Finally, we offer a specific speculation, which seems both, physically plausible and welcome, likewise simplifying our interpretation. Actually, it seem un-forbidden to assume that there is unique (quantum law) for both, isolated and open quantum systems, which is represented by some operator (of still unknown characteristics), $\hat{U}^{(u)}$. The universality means that one may state:

$$\hat{U}^{(u)}(T_i) = \hat{U}^{(i)}(t^{(i)}),$$

including

$$\hat{U}^{(u)}(T_M) = \hat{U}(t^{(M)}),$$

where $\hat{U}(t^{(M)})$ is the unitary Schrodinger’s operator. Above, $\hat{U}^{(u)}(T_i)$ should be considered as a "representation" of $\hat{U}^{(u)}$ with respect to $T_i$.}
Certainly, to make sense, this hypothesis should firstly provide us with more precise physical meaning of the above ”representation” given above. Still, it significantly simplifies MTI, by assuming existence of unique quantum law at ”all [physical] levels” - cf. Penrose 1994 (p. 308).

Fortunately, if this hypothesis would finally prove unjustified, the MTI itself would not ”suffer” from this, at all.]

12. THE ISOLATED COMPOSITE SYSTEM ”OBJECT PLUS APPARATUS”

Reducibility of MTI onto the interpretation given in Section 7 is probably obvious (cf. Section 10). Here we show that the inverse does not prove correct.

The real object of the von Neumann’s theory is not the ”object” alone, but the composite system, ”object + apparatus (O+A)”. In the original theory, the system O+A is considered isolated - meaning that one must consider the Schrodinger equation valid for O+A.

As regards O+A the Scheme (S1) appears extended as:

\[ \Psi \chi \rightarrow \Psi_1 \chi_1, \quad W_1 \]

or

\[ \Psi \chi \rightarrow \Psi_2 \chi_2, \quad W_2 \]

or ...

\[ \Psi \chi \rightarrow \Psi_n \chi_n, \quad W_n \]

etc. By \( \Psi \)s we denote the states of the ”object”, and by \( \chi \)s the states of the ”apparatus”.

Again, one can recognize the ”channels” in (S2), and therefore, in analogy with (10), may introduce the operators \( \hat{V}_i \) (instead of \( \hat{U}_i \)s of Section 7).

However, the set \( \{ \hat{V}_i \} \) does not necessarily lead to MTI !

This can be seen as follows. The operators \( \hat{V}_i \) are defined by:

\[ \hat{V}_i \Psi \chi = c_i \Psi_i \chi_i, \quad (17) \]

but which could be in accordance with the Schrodinger equation:

\[ \hat{U} \Psi \chi = \sum_i d_i \Psi_i \chi_i, \quad (18) \]

where \( \hat{U} \) is the unitary operator of the Schredinger law.

As it can be easily seen, this can be fulfilled if one may state \( c_i = d_i, \forall i \), and:

\[ \hat{U} = \sum \hat{V}_i, \quad (19) \]
Therefore, as it was told above (cf. also Section 10), the very existence of the operators \( \hat{V}_i \) - in analogy with (10) - does not necessarily lead to MTI, but - under the condition (19) - leads to the von Neumann’s theory.

Needless to say, in the von Neumann’s theory, the expression (19) - cf. Section 4 - refers to both, an ensemble of pairs, O+A, and to each single pair. Therefore, as the real physical process, in this theory, appears the Schrödinger equation - and how otherwise could be - "in" the "macroscopic" Time? Then, the operators \( \hat{V}_i \) appear artificial, without any physical meaning, and can be eventually used as a mathematical tool. And this is exactly from what suffers the operators \( \hat{U}_i \) of Section 7, in the same context.

Relative to this, MTI states exactly opposite: in terms of this Section, MTI states that each operator (i.e., the corresponding "channel") \( \hat{V}_i \) refers to the real physical process. Then, if (19) would appear admissible, the unitary operator, \( \hat{U} \) - cf. l.h.s. of (19) - appears unphysical, artificial, and can be only used for mathematical convenience. Certainly, in full analogy one gives an answer to the question raised in Section 10 concerning whether the very existence of the operators \( \hat{U}_i \) (of Section 7) can be seen equivalent with MTI, thus justifying told therein, and in the beginning of this Section.

13. THE OPEN SYSTEM O+A

The previous analysis refers to the original von Neumann’s theory. However, the system O+A is really an open system, which is due to the openness of the "apparatus".

The openness of the "apparatus" is not just a fruitful hypothesis in the modern decoherence theory. It is a statement that also follows from the more elaborated von Neumann’s theory. Actually, as it was shown by Araki and Yanase 1960 and Yanase 1961, the quantum measurement process breaks some conservation laws concerning the system O+A. Certainly, this implies existence of the "environment" (E), which should provide validity of the conservation laws - certainly, now for the "whole", O+A+E. Furthermore, as it was shown by Zurek 1983 (p. 93), this task can be done correctly if there is a part E" of the environment which is not in correlation with the "rest", O+A+E', E'-the correlated part of the environment ; E = E' + E". In other words, the part E" is "here just to pay for the balance".

Therefore, the composite system O+A should be considered in analogy with the object O; i.e., the scheme (S2) should be considered in analogy with the scheme (S1).

However, if the states of the "apparatus" in (S2), \( \chi \), should be interpreted as mutually macroscopically distinguishable, then the direct interpretation in terms of many Time axes - which should also refer to the macroscopic variables - would appear incorrect. Actually, one generally deals with the macroscopic variables as the objects of the "macroscopic" Time, bearing classical reality (determinism, causality and locality).

However, there is another positive statement of the measurement theories, which makes MTI sound even in this context; this is the amplification process. Actually, according to this, the "apparatus" consists in the two parts, the "microscopic" one, A', and the "macroscopic" one, A" ; A = A' + A". Then the measurement has the two stages:

\[
\Psi_{O \phi A'} \Phi_{A'} \xrightarrow{T_i} \Psi_{O_i \phi A'_i} \Phi_{A'} \xrightarrow{\text{amplifier}} \Psi_{O_i \phi A'_i} \Phi_{A''_i}.
\]  

(20)
The first stage (cf. the 1st arrow from the left) establishes the correlations between O and A'. Since both systems, O and A', are the "microscopic" ones, one may apply the main interpretational rule of MTI onto O + A'; note: $\chi_A \equiv \phi_A'\Phi_A''$, $\chi_A$ appearing in (17). The second stage (cf. the second arrow) is the amplification process. It consists in transferring the information "contained" in A', to the "macroscopic" part, A". This transfer can be complex, and we shall postpone its discussion until subsection 20.6. Here we just want to note that the second stage does not admit for applying the stochastic change of Time axis, and which is due to the macrosopicity of A". [Note: everything still comes by definition, but will be strongly justified in Section 20.] It is essential to note that the operators $\hat{V}_i$ in Section 12 now appear as just effective transformations, i.e. (contrary to $\hat{U}_i$s of Section 7) not defining the Time axes, $T_i$. Rather, $\hat{V}_i$s are defined by (17), i.e., by $\hat{V}_i\Psi_{O\phi_A'\Phi_A''} = \Psi_{O\phi_A'\Phi_A''}i$, without stating the details concerning the involved, local Times, which are distinguished in (20).

It can not be overemphasized that each system, O, A’, and A” has its own ”pure” state in each stage of the process, and allows for the complete application of MTI in the first stage of the process (20).

Therefore, we conclude that applicability of MTI concerning O+A requires existence of the amplification process.

14. THE "WHOLE" O+A+E

Certainly, the complete analysis refers to the ”whole”, O+A+E = O + (A’+A”) + (E’+E”). For the simplicity we shall omit the later, i.e., the precise ”decomposition” of the apparatus and of the environment, bearing in mind that, in accordance to the previous Section, the ”correlated” part of the environment, E’, should consist in the two parts, the ”microscopic” one, E’ and the ”macroscopic” one, E”i. Further, we shall also assume the underlying, local amplification processes concerning both, A, and E’.

Now the contents of the previous Sections can be summarized as follows:

$$\Psi_{O\chi_A\lambda_{E'}\kappa_{E''}} \rightarrow \Psi_{O{i}\chi_{A'i}\lambda_{E'}\kappa_{E''}} \rightarrow \Psi_{O{i}\chi_{A'i}\lambda_{E'}i\kappa_{E''}}, \quad W_i,$$

without the details (the ”parts”, and amplifications), and with obvious notation.

Let us note: The evolution of the ”whole” clearly distinguishes the two parts of the "whole". The one part, O+A+E’, bears the correlations. The second one, E”, does not. Certainly, the evolution of the first part is complex, involving the different stages concerning each ”arrow” in (21). Further, it bears existence of the local Time axes for each single ”whole” - i.e., in each single run of the measurement. On the other side, there is the uncorrelated part E” of the environment, which is ”here just to pay for the balance”. The quantum state of E” does not significantly change - as it is presented above (cf. Zurek 1983, p. 93).

Now, to this end, the main interpretational rule of MTI states: a single ”whole” O+A+E can not be considered to evolve according to unique Time axis. Furthermore, due to the complexity of the ”whole”, each single ”whole” has its own set of the local Time axes, each being governed by the corresponding probability.
15. QUANTUM STATE OF THE ENSEMBLE

The expression (21) refers to each single "whole". Due to MTI, each single "whole" has its own final ("pure") state:

$$\Phi_{fO+A+E} = \Psi_{Oi}\chi_{Ai}\lambda_{E'i}\kappa_{E''}, \quad (22)$$

with some probability,

$$W_i = \lim_{N \to \infty} N_i/N,$$

where $N_i$ represents the number of appearance of the $i$-th outcome, while $N$ represents the total number of the outcomes.

Now, by definition, the state of the ensemble of $N$ elements (here: single "wholes") reads:

$$\hat{\rho}_{fO+A+E} = \sum_i W_i \hat{P}_i \hat{\rho}_{fO+A+E} \otimes |\kappa_{E''}\rangle\langle \kappa_{E''}|, \quad (23)$$

where $\hat{P}_{fO+A+E} \equiv |\Psi_{Oi}\rangle\langle \Psi_{Oi}| \otimes |\chi_{Ai}\rangle\langle \chi_{Ai}| \otimes |\lambda_{E'i}\rangle\langle \lambda_{E'i}|$.

It is essential to note: (i) The state (23) is exactly the one defined by the "projection postulate", (ii) Ensemble of each subsystem, O, A, E (and their parts distinguished above) has unique "mixed" state, e.g.:

$$\hat{\rho}_O = Tr_{A+E} \hat{\rho}_{fO+A+E} = \sum_i W_i |\Psi_{Oi}\rangle\langle \Psi_{Oi}|, \quad (24)$$

and analogously for A, E, and their "parts".

And at this point we meet the two distinctions between MTI and the usual ensemble-interpretation. The one will be presented in Section 17, while there is another one: The "mixture" (24) really is the "improper mixture" (cf. d’Espagnat 1976), but it refers exclusively to the ensemble point of view. Here, in MTI, the objective is the single system (O, O+A, or O+A+E). Now, given the state of each single system, the state of the ensemble directly follows. But, and this is the point, there is no any doubt concerning the quantum state of any single system in MTI. I.e., the problem of the "improper mixtures" disappears in MTI, due to being concerned with the single systems.

16. IRELEVANCE OF THE "STATE REDUCTION PROCESS"

Now we are prepared to give probably the very central implication of MTI: physical irrelevance (i.e., unphysical character) of the von Neumann’s "state reduction process".

As it was emphasized in Section 14, the "whole" O+A+E admits for preserving the conservation laws (cf. the refs. therein), but can not be considered as an object of unique Time. Furthermore, there is a collection of the local Time axes for each single "whole". Needless to say, this physical situation can not be considered equivalent with existence of the unique, "macroscopic" Time, as is the case in the von Neumann’s theory, in which the whole ensemble, likewise each particular (single) "whole", is an object of the "macroscopic" Time.

The unique Time in the von Neumann’s theory defines the Schrodinger law as the quantum law for both, single "whole", likewise for an ensemble of the "wholes". The Schrodinger equation bears linearity and establishes the correlations:

$$\hat{U}\Psi_{O_i\chi_{Ai}} = \sum c_i \Psi_{O_i\chi_{Ai}} \Phi_{E'i}, \quad (25)$$
and therefore calls for the "reduction process".

However, in MTI, the final state (23) is obtained by the main interpretational rule of MTI, bearing the different sets of the local Time axes for each single "whole". Certainly (cf. also Section 17 for some details), this makes the Schrodinger evolution unphysical, and therefore, the "state reduction process" unnecessary and unphysical.

17. THE ISOLATED O+A+E

Now one may state a question raised in Section 10 (and essentially answered in section 12), but with regard to the "whole", O+A+E.

Actually, the Scheme (S2) should be extended: everywhere instead of $\Psi\chi$, should be put $\Psi\chi\Phi$, where $\Phi$ refers to the state of the environment. Again, there appear the "channels" of the type $\Psi\chi\Phi \rightarrow \Psi_i\chi_i\Phi_i$, which are governed by some (also - cf. Section 13 - effective) evolution operators $\hat{W}_i$ - instead of the operators $\hat{U}_i$ (cf. Section 7) for the "object" alone, and (cf. Section 13) the effective operators $\hat{V}_i$ for the composite system, O+A.

Again, the very existence of the operators $\hat{W}_i$ does not appear equivalent with MTI, in the exactly the same way as it was shown in Section 12. And this is another point at which one meets significant distinction between MTI and the von Neumann’s theory. Let us briefly repeat what was told in Section 12, but here bearing in mind the "whole".

The existence of $\hat{W}_i$s (even if these were not effective operators) is not in contradiction with the von Neumann’s theory, while MTI is in contradiction with the von Neumann’s theory. Actually, the Schrodinger law appears to be the real physical process in the von Neumann’s theory, while then the operators $\hat{W}_i$ prove just to be there for mathematical convenience, bearing no element of reality.

On the contrary, in MTI one refers the operators $\hat{W}_i$ to the real physical processes concerning the single "wholes", while the Schrodinger equation appears unphysical.

Certainly, the expression $\hat{W}_i \equiv \hat{W}_i(t^{(M)})$ represents reduction of MTI onto the "macroscopic" Time - i.e., presenting $\hat{W}_i$s in terms of the "macroscopic" instants. As it is stated above: this reduction allows also for the von Neumann’s interpretation, this reduction of MTI can not be considered equivalent with MTI itself, and necessarily calls for the Many Times - cf. on the end of Section 10 - instead of only one Time.

18. TENTATIVE CONCLUSION

We have consistently applied the main interpretation rule of MTI to the composite systems, O+A, and O+A+E, with no new hypothesis.

The application leads to: (i) Necessity of the amplification process in the measurement process, (ii) Obtaining the "mixed" state of each subsystem in exactly the same form as stated by the "projection postulate", (iii) Unphysical character of the Schrodinger equation concerning the "whole", O+A+E, and therefore unphysical character of the "state reduction process", and (iv) Nonequivalence of MTI with the von Neumann’s theory, or with the reduction of MTI onto the "macroscopic" Time.

Finally, each subsystem of a single "whole" has a definite quantum state - which is the (quantum) determinism - (cf. Section 1 for definition). On the other side, each local
Time refers to the unique transition, i.e., to the unique final state - which is the (quantum) causality. Therefore, the analysis concerning the composite systems justifies the analysis, which refers to the "object" alone. Finally, MTI reduces the quantum measurement process onto the search for the quantum effect, which would allow for the local, stochastic change of Time axis; this gives an "interpretation" of the probabilities, $W_i$, of the schemes (S1) and (S2).

19. SOME CRITICAL REMARKS

One may note that the final state $\hat{\rho}_{fO+A+E}$, Eq. (23), comes from MTI by definition. On the other side, one would expect that the process of change of Time should bear a deeper physical foundation. Thus one may wonder if the rules of MTI might bear some generality, and probably wider applicability.

On the other side, a "solution by definition" virtually bears danger. E.g., if understood literally, by this one might "explain everything", by simple asserting that "there is a such Time axis"...

All this actually points to a need for axiomatization of MTI.

20. AXIOMATIZATION OF MTI. A NEW PHYSICAL PICTURE

Here we shall adopt the plausible definition of the "macroscopic" ("classical") systems which is usual in, e.g., modern decoherence theory: by the "macroscopic" systems we shall assume the many-particle systems which are in unavoidable interactions with their environments. [Certainly, the "microscopic" ("quantum") systems are those which can be, at least in principle, considered isolated.] Further, we assume existence of the macroscopic systems as phenomenological data, without dealing with - in epistemological terms - the question of becoming of the data; still, this does not mean that the "data" can not be eventually deduced within MTI.

Finally, we assume that each measurement-like interaction defines a set of possible Time axes, while the very possibility of changing Time axis requires existence of a part $E'$ of environment, which "should pay for the balance" (cf. Sections 13 and 14). An isolated quantum system is certainly an object of "macroscopic" Time, $T_M$.

Bearing these assumptions in mind, we shall formulate the particular propositions, and investigate some of their basic implications and predictions.

20.1 The propositions of MTI

(P1) Each physical system should be considered as an object of one and only one Time axis. Each Time axis defines "its own" physical laws.

(P2) Each two, mutually relatively strongly interacting systems, have a common Time axis.

Let us briefly clarify the two propositions.

First, (P1) establishes that a physical system evolves due to a definite Time axis. Therefore, the set of the alternative Time axes appears as a sort of the classical stochastic variable - there are no the "coherent mixtures" of the different Time axes. Each physical
situation is governed by a physical law, but the form of the law is determined by the actual Time axis.

As regards (P2), one should note that a system can interact with many physical systems; i.e., there might be a numerous set of interaction Hamiltonians, which depend upon the observables of the actual system. Yet, only some of these Hamiltonians would in general appear "effective", i.e., non-negligible. This defines what was called in (P2) as "relatively strong interaction". Certainly, (P2) states that not necessarily all the interacting systems should be considered to have a Time axis in common; just some of them, which are "relatively strongly" interacting. Needless to say, this provides locality of the Time axes. [Note: this locality does not have much in common with the "locality" in the context of the EPR paradox - to be discussed in subsection 20.9.]

Therefore, the above propositions provides us with determinism, causality and locality concerning the isolated quantum systems, likewise the objects of the quantum measurement processes.

20.2 Existence of the "macroscopic" Time

This is the first implication (prediction) of the proposition (P2).

As we told above, we assume existence of the macroscopic systems, \(S_1, S_2, \ldots S_n\). By definition, each macroscopic system is an open system, i.e., the complete picture concerning the macroscopic systems is the next one: \((S_1 + E_1), (S_2 + E_2), \ldots (S_n + E_n)\), where \(E_i\) denote the corresponding environments.

This situation can be re-written as \(S + E\), where \(S = \sum_i S_i\), and \(E = \sum_i E_i\); let us refer to \(S\) and \(E\) as to the macroscopic part of the Universe, and its environment, respectively.

However, it is the very nature of the macroscopic systems that they are, pairwise, in interaction, for instance: \(S_1 - S_2, S_2 - S_3, \ldots\), thus making the "chain" of interacting systems. Let us assume that all these interactions are relatively strong.

Then there is an immediate consequence of the proposition (P2): as regards the above "chain", the proposition (P2) implies that the "chain" should be considered as an object of the same Time - which, by definition, is the "macroscopic" Time, measured by the macroscopic clocks.

Certainly, the two parts of the "chain", \(S_1\) and \(S_n\), although mutually only weakly interacting, are both objects of the "macroscopic" Time. But this is not due to its mutual interaction, but due to the "chain"-character of the system \(S\). And everything directly applies to the environment \(E\), likewise to \(S+E\).

20.3 The "structure" of the "macroscopic world"

Let us refer to the above defined system \(S + E\) as to the "macroscopic world".

Above, we have assumed that each macroscopic system, \(S_i\), could be considered to be "solid". However, each system has its own "structure" - divisibility into the subsystems. And not all the subsystems would be "relatively strongly" interacting with the rest of the macroscopic body. This highly plausible notion further leads to making another picture of "structure" of macroscopic body (further : body): there are some parts ("microscopic")
subsystems), which are relatively weakly interacting with the mutually-relatively-strongly-interacting pieces ("macroscopic" subsystems) of the body. Now, the later is a part of the body which directly refers to the "macroscopic" Time. Still, the choice of the Time axis depends on the locally strongest interaction. Therefore, in so far as the "microscopic" part of the body is in relatively strong interaction with the "macroscopic" one, it is also an object of $T_M$.

**Note:** what is the "microscopic", and what the "macroscopic" part(s) of a macroscopic body is here undefined. However, we believe that in each particular situation, this can be properly defined without any serious obstacles.

### 20.4 "Embedding" of the macroscopic bodies in $T_M$. Origin og the macroscopic quantum fluctuations

One may wonder if the macroscopic bodies can be considered as the objects of stochastic change of Time. But the answer is: NO, despite the fact that the macroscopic bodies are (cf. above) defined as the open quantum systems. This is simply because that there is no such a big environment (more precisely: the part E”), which should "pay for the balance".

However, strictly speaking, this refers to the "macroscopic" subsystems of the macroscopic bodies: these are "embedded" in $T_M$. Still, the very existence of the "microscopic" pieces defined above, allow for the next considerations: Let us consider the two bodies, $S_1$ and $S_2$; the "microscopic" pieces are $\sigma_1$ and $\sigma_2$, respectively. The interaction between $\sigma_1$ and $\sigma_2$ might exceed all the other interactions: $\sigma_1 - S'_1$, $\sigma_1 - S'_2$, $\sigma_2 - S'_1$, $\sigma_2 - S'_2$; here : $S'_i = S_i/\sigma_i$, $i = 1, 2$.

Now, (P2) applies to the (locally, relatively strong) interaction $\sigma_1 - \sigma_2$. If the two systems are both sufficiently "microscopic" (cf. counterexample on the beginning of this subsection), one meets the possibility of the (local) change of Time axis, concerning the pair $\sigma_1 + \sigma_2$. Now the amplification from $\sigma_{1,2}$ to $S_{1,2}$ provides us with another prediction of MTI which can be eventually recognized as the origin of the "macroscopic quantum fluctuations".

OK, but what when (measured by macroscopic clock) this interaction would become "weak"? The answer will be given in subsection 20.6. Let us just remind that then the interactions $\sigma_1 - S'_1$, and $\sigma_2 - S'_2$, become relatively strong interactions.

### 20.5 The Hamiltonian equations

As it was told in introduction of this Section and in subsections 20.1 and 20.2, both, the isolated "microscopic", and the open "macroscopic" systems are the objects of the "macroscopic" Time, $T_M$. Due to (P1), there is another direct "prediction".

Let us for simplicity be concerned with the mechanical systems. Then (P1) implies - cf. the second part of (P1) - that both kinds of systems (classical and quantum) should be governed by the same kind of physical law(s). And this is exactly the case - e.g., the Hamiltonian equations. [At this point one meets the limitations of MTI: we give the formal correspondence between the classical and quantum systems, without entering the subtleties concerning the corresponding state spaces, and the deeper questions concerning the physical interpretation of the "wave function".]
20.6 The amplification process

In Section 13 we have distinguished the process of amplification as a substantial stage in the measurement process. Let us put this with some detail.

The situation we are concerned with is the next one: a microscopic "object" is in the measurement-like interaction with a macroscopic apparatus, A. The result of this interaction should fit (S2).

Before the interaction, the "microscopic" part A' of the apparatus is in relatively strong interaction with the "rest", A''(= A/A'). Due to (P2), then A' is also an object of $T_M$. When the interaction between O and A' becomes dominant, the first stage of the measurement process (cf. (20)) can proceed. Note: then the interaction between A' and A'' becomes negligible, but not exactly zero; i.e., A' is an open system, while A'' is not (cf. 20.4) an object of change of Time, for the two reasons: (a) it is weakly interacting with A', and (b) A'' is embedded in $T_M$.

Due to the openness of A', the composite system O+A' is also an open system, and, according to (P2), might become an object of the stochastic change of Time:

$$\Psi_O\phi_{A'} \xrightarrow{T_i} \Psi_Oi\phi_{A'i}.$$  \hspace{1cm} (26)

However, after some time (measured by macroscopic clock), the interaction between O and A' will cease to be dominant. Then the dynamics of O, according to MTI, becomes governed by the Schrodinger law.

On the other side, however, the interaction of A' with A'' again becomes dominant, and this is the beginning of the second stage (cf. the second arrow in (20)) of the measurement: the amplification process. Then the information "stored" in A', transfers to A'', thus giving rise to:

$$\phi_{A'i}\Phi_{A''i} \xrightarrow{amplification} \phi_{A'i}\Phi_{A''i}.$$  \hspace{1cm} (27)

There are a few scenarios for (27). They can be classified relative to the next criteria: whether one considers QM universally valid or not, and concerning the "structure" of A'', which might provide the different stages in the amplification itself. Here we shall refer to probably the simplest situation: universally valid QM, without the "stages" in amplification.

Now, MTI implies: A'' is an object of $T_M$. Then the direct amplification (interaction of A' with A''), due to "embedding" of A'' in $T_M$, would mean "glueing" of A' to $T_M$; i.e., A' survives another change of Time, and the final Time (with certainty) is $T_M$. Now, in the context of the universally valid QM, MTI implies that the physical law is the Schrodinger law, i.e.:

$$\phi_{A'i}\Phi_{A''i} = \hat{U}\phi_{A'i}\Phi_{A''},$$  \hspace{1cm} (28)

where $\hat{U}$ is the unitary Schrodinger operator concerning the composite system A'+A''. (Needless to say, the expression (28) calls for the specific interaction Hamiltonians, which can be found in Dugić 1996/97.)

[Finally, the above scenario refers to an ideal quantum measurement, while the "steps" in amplification might involve the slight changes in the state of A' - non-ideal measurement.]
20.7 Quantum complementarity

Everywhere above we have been concerned with the fixed measurement situation. Certainly, for the different measurements one meets the different outcomes, which involve the different final states (e.g., $\Psi_i$ for the "object"), and the corresponding probabilities $W_i$. And those measurements which have identical outcomes, appear mutually equivalent in MTI.

Here we meet the basis for "explanation" of the quantum complementarity within MTI. The different outcomes define the different, mutually irreducible and incompatible distributions of the Time axes. Actually, due to (P1) one can provide one, and only one (definite) Time axis for an "object", and therefore a definite measurement, which refers to the actual Time-axes distribution. In other words: (P1) implies mutual exclusiveness ("incompatibility") of the different Time-axes distributions, which is the MTI form of the famous quantum complementarity.

20.8 Macroscopic irreversibility

MTI implies macroscopic irreversibility!

In order to prove this claim, we shall be concerned with an "object" interacting with the macroscopic bodies. For the simplicity, we shall be concerned only with the states of the "object", but everything directly refers also to the states of the "apparatus" and "environment".

Let us consider a "hystory" of an "object"; this is a "chain" of sequences of the free (Schrödinger) evolutions, and of the measurement-like interactions with the "microscopic" pieces of the macroscopic bodies. And let us assume that the initial state of the "object" is a "pure" state $\Psi$. Finally, let us assume that the "object" interacts first with a macroscopic body $M_1$.

Then MTI leads to a (stochastic) transition of state of the "object":

$$\Psi \rightarrow \chi_1.$$ (29)

After this transition the "object" evolves according to the Schrödinger law:

$$\chi_t = \hat{U}(t)\chi,$$ (30)

and let us assume that in an instant $t$, the "object" interacts with another macroscopic body $M_2$. Then (another stochastic transition):

$$\chi_t \rightarrow \kappa_2,$$ (31)

and so on.

Then the "hystory" of the "object" reads:

$$\Psi \xrightarrow{T_1} \chi_1 \xrightarrow{T_M} \chi_t \xrightarrow{T_2'} \kappa_2 \ldots.$$ (32)

And this "hystory" is not reversible.
To see this, let us be concerned with the state $\kappa_2$ as the initial state. Then, bearing in mind the macroscopic bodies on the proper "places" in the "hystory", the inverse of (32) reads:

$$\kappa_2 \xrightarrow{T_2'} \chi_1 \xrightarrow{T_M} \chi_1 \xrightarrow{T_1} \Psi \ldots$$

(33)

Actually, MTI states that, e.g., when interacting with $M_2$, the "object" can "meet" the axis $T_2'$, but only with some probability $W_2'$. If this would occur, then the transition from $\chi_1$ to $\Psi$ - which would be due to $T_1$ - can also be obtained only with some probability $W_1$. Therefore, an ensemble of the "objects" initially prepared in the state $\kappa_2$, would split, and the hystory (33) appears admissible only with probability:

$$W_1 \cdot W_2'.$$

(34)

The expression (34) is easy to be generalized by:

$$\Pi_{i=1}^N W_i \to 0, \quad N \to \infty,$$

(35)

while

$$\sum_{i=1}^N W_i \neq 1,$$

(36)

due to the fact that, generally, the probabilities $W_i$ refer to the different, mutually exclusive, probability distributions.

Needless to say, the expressions (35) and (36) represent a formal expression of the macroscopic irreversibility in MTI.

### 20.9 EPR correlations

Unfortunately, MTI does not have much to say about the "EPR paradox". Each EPR pair consists in the two microscopic (quantum) systems, a system $S_1$, and $S_2$. Each of them, likewise the pair itself, is an isolated quantum system.

According to MTI, since there is no "environment", the pair can not meet the change of Time axis - unless a measurement by an "apparatus" is prepared.

Therefore, the EPR pairs are necessarily the objects of the "macroscopic" Time, while all the conservation laws being exactly fulfilled. Now, MTI implies that the pairs evolve according to the Schrodinger equation, which - as is well known - implies establising of the quantum correlations:

$$\Psi_1 \chi_2 \xrightarrow{T_M} \sum_i c_i \Psi_{1i} \chi_{2i},$$

(37)

with obvious notation and $\langle \Psi_{1i} | \Psi_{1j} \rangle = \delta_{ij}, \langle \chi_{2i} | \chi_{2j} \rangle = \delta_{ij}$.

Now MTI implies that the pair, $S_1 + S_2$, represents an object of the evolution due to $T_M$, which can not be told for the subsystems, $S_1$, and $S_2$. Actually, as it is distinguished by d’Espagnat 1976, one can not ascribe a definite quantum state to the subsystem’s - rather, they are in mutual quantum correlations (the famous quantum nonseparability).

But this is substantial matter in MTI. Note: everywhere above, we defined the physical Time with regard to a definite state of the actual system. Without a definite
state, MTI does not refer a definite Time axis to the actual system. Now, due to \((P1)\) one can say nothing about evolution of either subsystem, \(S_1\), or \(S_2\).

Finally, the pair as a whole is an object of definite Time axis, and everything told above refers to each single pair, but not to the subsystems \((S_1, \text{and/or} \ S_2)\). And: the "locality" in this context, which refer to interaction between \(S_1\) and \(S_2\) - which do not have the definite Time axes - is not the locality dealt with above, which refers to definite Time of the actual system.

20.10 Relation to the "objective reduction" of Penrose

In his recent book Penrose 1994 has pointed out a need for a new paradigm, the so-called, "objective reduction (OR)", which would prove to be a real physical process/effect allowing for what is called the "state reduction process (collapse)" by von Neumann.

Here we just point out that the process of stochastic change of Time axis in MTI can be considered as a candidate for "OR" of Penrose. For both "processes" have the same final efect, bearing physical reality with respect to the elements of the corresponding Hilbert state space.

21. COMPARISON OF MTI WITH SOME MEASUREMENT THEORIES

As a matter of fact, most of the theories/interpretations deal with the "object" - instead of the composite systems, \(O+A\), and/or \(O+A+E\). But, as it was distinguished above, this approach proves to be somewhat naive. Still, we shall compare the basics of MTI with some prominent theories.

21.1 MWI of Everett

It is probably obvious that MTI and MWI of Everett 1957 do not have very much in common. Still, there is a small danger for misunderstanding the "channels" of MTI as the "branches" of MWI. This is the main object of this Section.

As distinct from MTI, MWI deals with unique Time, and therefore with the Schrodinger equation concerning (isolated) \(O+A\); i.e., there is no environment in this theory. Finally, the "branching" is considered as global, metaphysical process, while the "channels" refer to the real, stochastic, local processes, which keep uniqueness of the Universe.

21.2 Von Neumann’s theory

Throughout the text we have strongly emphasized the distinctions with this regard. As the most important distinction appears unnecessity of the "state reduction process" (of the von Neumann’s theory), which actually becomes an unphysical process. And the measurement process reduces onto the search for quantum effect, which would allow for the local, stochastic change of Time.

21.3 Some modern theories

There is a set of modern theories which bear mutual similarities, at least as regards our goal - comparison with MTI. Particularly, we mean the GRW theory of Ghirardi et al
1986, RPI theory of Mensky 1993, the method of stochastic Schrödinger equation of Diosi 1989, likewise the recent interpretation (in the same context) of Kist et al 1998.

All these theories are concerned with a search for a quantum law, which would govern the evolution of the "object" alone; certainly, everything expressed in $T_M$. And this is our impression that these theories, altogether, narrow down the list of candidates for a general quantum law for the quantum "objects", the existence of which has just been presumed - cf. Section 7 - but not considered in detail.

Especially, the method of stochastic Schrödinger equation drags attention. And especially the interpretation of Kist et al. Actually, prima facie, this interpretation bears significant similarities with MTI. Instead dealing with the details, we shall just refer to the basic notions in this respect.

First, MTI deals with the composite systems, O+A and O+A+E. These considerations justify the MTI statements concerning the "object" alone. Now, when expressed in terms of $T_M$, and with regard to the "object" alone, MTI reduces onto the notions raised in Section 7. And this really bears significant similarities with the interpretation of Kist et al. However, as it follows from the Sections 12, this interpretation appears just as a model of MTI reduced onto $T_M$.

Actually, MTI does not insist on a particular type/form of the operators $\hat{U}_i$ - cf. Sections 7. On the other side (cf. Sections 7 and 12), the very existence of these operators - no matter of which type - does not necessarily leads to MTI, but also to the standard von Neumann’s interpretation. Therefore, the interpretation of Kist et al, which deals only with the operators concerning the "objects" alone, is not equivalent with MTI. Furthermore, it can be considered only similar with a particular "reduction" of MTI onto the unique (universal) Time, and bearing in mind the "object" alone.

22. OUTLOOK

MTI does not call for new hypotheses, but is rather a proposal for new "re-reading" of the existing data concerning the quantum measurement process.

MTI is not equivalent with any existing measurement theory or interpretation. On the other side, it is reducible - expressible - onto the terms which refer to unique ("macroscopic") Time. To this end, the interpretation of Kist et al 1998, appears as a model of the "reduced MTI", as regards the "object" alone.

Still, MTI is consistent in both aspects, it is self-consistent, and also consistent with - in so far as we can see - all the positive statements of the quantum measurement theories.

Probably the main achievements of MTI appear to be unnecessity of the "state reduction process", and deducibility of the macroscopic irreversibility. This refers to the new physical picture concerning the "border territory" between the "microscopic" and "macroscopic" parts of the World, given in Section 20. And, to this end, it is very interesting to note: For rejecting the "reduction" (as a necessary quantum process), it is necessary to have the macroscopic (open quantum) systems as a part of the physical situation. On the other side, for deducing the macroscopic irreversibility, it is necessary to have the microscopic, quantum systems involved. This points to the interplay between the "micro" and "macro" in foundations of QM, and also points to the interaction as a
fundamental issue in QM. [Eventually, the results of Dugić 1996/7 can be of some interest in this concern.]
23. CONCLUSION

A particular, semi-epistemological definition of physical time provides a new paradigm in the quantum world. Particularly, in the quantum measurement process, a single "object" becomes an object of stochastic change of Time (Time axis). Each Time should be considered objective (real) for the actual "object", as the "macroscopic" Time is objective in classical physics. The possibility for changing Time refers to unique reference frame, and thus the introduced nonuniversality (nonuniqueness) of Time does not have much in common with nonuniversality of Time in the theory of relativity.

In the standard, ensemble-interpretation of QM, one meets the next situation: in due course of the quantum measurement one meets "indeterminism". As opposite to this, MTI keeps "determinism", but with regard to the different Times.

None existing theory/interpretation proves equivalent with MTI. On the other side, MTI seems consistent with all the positive statements of the existing measurement theories. This is the probably the basis for obtaining the main achievements of MTI: Rejecting the "state reduction process" as a necessary (and actual) physical process, and Deducibility of the macroscopic irreversibility - both trully ideals of each sound quantum-mechanical theory. Within MTI, the "measurement problem" basically reduces onto the search for a physical mechanism (effect), which would allow for the local, stochastic change of Time. Finally, we hope that this process can be recognized as the "objective reduction", as defined by Penrose 1994.

Appendix I

Within the Newton's theory of absolute time, the time "flows equably without regard to anything external". Let us therefore introduce the infinitesimal of this time, $dt_a$. Let us, on the other side, introduce the infinitesimal of the physical time measured by a clock - and, due to Newton, this time is not identical with the absolute time - by $dt_c$. Generally speaking one may state:

$$dt_c = g(t_a)dt_a.$$ (I.1)

Now, by ideal clock we mean any clock for which one may state $g(t_a) = 1$. I.e., there is (up to arbitrary additive constant) isomorphism between the two sets of instants (and therefore of the intervals) - $t_a$ of the "absolute" time, and $t_{ci}$ of the "ideal clock".

From the purely operational physical point of view, this admits for considering identity between the two Times - the "absolute" one, and the one measured by the "ideal clock". This identification is sometimes expressed (cf. Mignard 1983) by the phrase that "the modern 'atomic' clocks do both, 'produce', and measure Time".

This way one realizes that, from a purely operational physical point of view, physics can hardly ever say much more about Time, than it is directly presented by the "ideal clock".

Appendix II

Both "primitives" of our approach - cf. subsection 2.2 - follow from phenomenology - directly, or eventually by interpolation.
The dynamics $D$, Eq. (1), is actually an elementary fact of physical observation, bearing no conditionality. This is certainly the case with the ordering of the elements in $D$.

However, sometimes it is argued that, a priori, one can not make such ordering without the prior ordering with respect to the time instants. However, as it is well known - cf., e.g., Schuster 1961 - in the, so-called, ”relational theory of time”, this is shown to be incorrect. Furthermore, as Penrose 1994 states, it is just our psychology that inevitably calls for an a priori ordering in time. We should add: this a-priori-statement represents a ”simultaneous” observation and interpretation of the contents of observation.

Here, we advocate somewhat the opposite statement: we have the dynamics $D$, and let us postpone the (above mentioned) interpretation. Actually, the ordering in $D$ is unavoidable physical fact, which can be (and usually is) recorded, memorized, If unconscious, the memory contains a spatial ordering which can be one-one re-written in terms of the points $A, B, \ldots$ of the dynamics $D$, without requiring an a priori temporal ordering.

**Appendix III**

Another ”primitive” of our approach is the concept of ”Causality”, $C$.

This is also an element of the classical-physics phenomenology: existence of unique and continuous ”trajectory” in the state space of the system.

Still, this has a deeper physical background: Actually, it is usually (cf., e.g., Withrow 1979, p. 43) stated that there is a close connection between the (concept of) Time, and the order in the physical world.

The definition (3) a priori involves existence of the order. Thus Time becomes a sort of ”ordering principle” of the physical world, rather than just being an (real) axis of the ”time instants”. Certainly, the epistemological concept of ”order”, physically becomes the ”physical laws”.

Still, the definition (3) should be considered somewhat rudimentary. Actually, the definition (3) establishes existence of Time, without saying almost anything concerning the ”nature of Time” (cf. Withrow 1979) - which is still the subject of intense discussions and considerations; cf. e.g., Zeh 1992. In other words: according to (3), the classical-physics Time just exists, without involving the details concerning the diverse discussions concerning the ”nature of Time”.

Let us finish by reminding that ”Causality” is physically equivalent with existence of physical laws, i.e., with the concepts of classical determinism and causality (cf. Section 1 for definitions).

**Appendix IV**

The definition (3) essentially establishes equivalence of the concept of physical Time, and physical dynamics, Eq. (2). This equivalence can be justified as follows.

First, in the Newton’s theory of time, the concept of physical dynamics, $D_p$, naturally follows.

On the other side, the definition (3) gives a possibility for stating physical definition of Time, Eq.(3). And this is logically just inverse to the above statement. In this context, it is of secondary importance if the instants in Eq. (3) are (non)unique. However, by
**definition**, we assume that if the instant $t_A^{(M)}$ is fixed, then the instant $t_B^{(M)}$ should be considered unique.

Therefore, the definition (3) establishes Time as a sort of "derivative" of the physical dynamics.

Now, although following from the different backgrounds, the these two statements justify physical equivalence of Time, and the physical dynamics.

**Appendix V**

Rigorously speaking, existence of unique and continuous "trajectory" concerning the i-th "Causality", $C_i$, is a matter of question, which is here assumed valid, at least for the simplicity.

Still, we believe that this assumption is not necessary, but that one may define some "generalized 'Causality' ", which would necessarily lead to the definition of "generalized Time", thus opening the question whether the microscopic Times, $T_i$, can be considered completely physically equivalent with $T_M$.

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