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Mott's Cloud-Chamber Theory Made Explicit and the Relative-Collapse Interpretation of Quantum Mechanics Thus Obtained

Fedor Herbut[1]

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It is pointed out that the concept of a shiftable split between object and subject with a well-defined subject, introduced and utilized in two preceding articles of the author, is present in Mott's historical cloud-chamber measurement theory. The crucial question of the occurrence of the subject events (the main constituents of the subject) is also given a tacit answer in Mott's text. When Mott's theory is made sufficiently explicit, the object–subject complementarity principle (an elaborated form of Bohr's macroscopic complementarity principle) emerges. The (individual-system) relative-collapse postulate, which appears as a natural completion of Born's (ensemble) postulate, takes form in it. The proposed interpretation is compared with the many-worlds and the modal approaches, which share with the former the idea of nondestruction of coherence (in contrast to interpretations that contain the idea of an absolute, i.e., observer-independent collapse, which destroys coherence irrevocably).

1. INTRODUCTION

Analyzing the famous theory of Mott (1929) of the quantum mechanical processes that go on in the Wilson cloud chamber, especially filling in the tacit elements of Mott's rather terse discussion, a new, purely quantum mechanical measurement theory and interpretation of quantum mechanics (QM) is obtained.

Section 2 gives the historical roots of the proposed interpretation. In Section 3 the concept of an object–subject split with a well-defined subject (from previous work) is summed up and applied to Mott's theory. In Section 4 stock is taken of the salient points. Section 5 is devoted to the exposition of the object–subject complementarity principle (an elaborated form of Bohr's

[1] Faculty of Physics, University of Belgrade, P.O. Box 368, 11001 Beograd, Yugoslavia.

macroscopic complementarity principle), the main constituent of which is the relative-collapse postulate. In Section 6 comparison is made with Everett's and the modal interpretations of QM, which are closest to the advocated approach. In Section 7 some concluding remarks are presented.

2. HISTORICAL ROOTS

In 1961 N. Bohr writes (Bohr, 1961):

"The main point here is the distinction between the *objects* under investigation and the *measuring instruments* which serve to define, in classical terms, the conditions under which the phenomena appear." (Italics in the original.)

Bohr goes on (Bohr, 1961):

"It is only decisive that, in contrast to the proper measuring instruments, these bodies [he means "heavy bodies like diaphragms and shutters" mentioned in the preceding sentence] together with the particles would constitute the system to which the quantum-mechanical formalism has to be applied."

Shimony (1963) comments on this as follows:

"Bohr is saying that from one point of view the apparatus is described classically and from another, mutually exclusive point of view, it is described quantum mechanically. In other words, he is applying the principle of complementarity, which was originally formulated for microphysical phenomena, to a macroscopic piece of apparatus."

Two more points in Bohr's text are relevant and important for the issue of this article:

(i) It is claimed that some systems (in this case macroscopic ones) may and need not be included in the object of quantum mechanical description. Hence, Bohr appears to accept tacitly, and at least partially, *QM of extended validity* (i.e., the validity of QM also for classical objects). We are dealing here with what is called a shift of the cut between the object (of quantum mechanical description) and the rest of the universe (roughly: the subject). (This idea is elaborated in the next section).

(ii) Bohr's macroscopic complementarity (as Shimony's above comment suggests we call it) seems to me lacking an explicit answer to an obvious question:

What happens to possible quantum mechanical *coherence* (or coherent mixture) in the state of the microsystem-plus-macrosystem when one abandons the alternative in which the macrosystem belongs to the quantum object and one goes over to the other alternative, in which it is part of the measuring instrument?

Studying some tacit elements in Mott's (1929) cloud-chamber theory below, we are going to elaborate Bohr's macroscopic complementarity principle into what we shall call the object–subject complementarity principle (expounded in Section 5). The latter is intended to complete the former essentially regarding point (ii).

Bohr's macroscopic complementarity appears "in his most careful writing," as Shimony (1963) puts it, rather late both in his work on QM and in the development of QM itself. But the same idea can be found, perhaps even in a clearer form, much earlier, in the mentioned article of Mott.

Mott's (1929) article is of lasting significance. It appeared under the title "The Wave Mechanics of α-Ray Tracks." The well-known measuring instrument called a Wilson cloud chamber is studied in it, utilizing, essentially, QM of extended validity. The author starts with the remark:

"In the theory of radioactive disintegration, as presented by Gamow, the α-particle is represented by a spherical wave which slowly leaks out of the nucleus. On the other hand, the α-particle, once emerged, has particle-like properties, the most striking being the ray tracks that it forms in a Wilson cloud chamber. It is a little difficult to picture how it is that an outgoing spherical wave can produce a straight track; we think intuitively that it should ionize atoms at random throughout space."

A little further, Mott says:

"If we consider the α-ray alone as the system under consideration, then the gas of the Wilson chamber must be considered as the means by which we observe the particle; so in this case we must consider the α-ray as a particle as soon as it is outside the nucleus, because that is the moment at which the observation is made. If, however, we consider the α-particle and the gas together as one system, then it is ionized atoms that we observe; interpreting the wave function should give us simply the probability that such and such an atom is ionized. Until this final interpretation is made, no mention should be made of the α-ray being a particle at all."

Further, Mott considers only two atoms, and, by solving the Schrödinger equation, he, finally, shows that the atoms cannot both be ionized unless they lie in a straight line with the radioactive nucleus. I will refer to two such atoms as "double atoms" throughout.

It seems to me that Mott is obviously dealing with Bohr's above-discussed macroscopic complementarity, and though his quoted physical picture of the cloud chamber is, perhaps, more revealing than Bohr's text, it is still very much lacking in completeness of expression. I will try to complete it in this investigation by making gradually explicit some of his tacit elements in the way I think he actually meant them.

Returning to relevant history, perhaps it is worth pointing out that also in Heisenberg's (1942) famous monograph on the uncertainty relations, which appeared first in 1930 (in German), one can find elements of quantum measurement theory in the Wilson chamber along the above-sketched ideas of Mott. The discussion presented is less clear for our purposes. (Some points that are important for this article are obscured in Heisenberg's text by his focusing attention on the uncertainty relations.)

Heisenberg refers besides to Mott also to an earlier article by Born (1926).

3. MOTT'S THEORY AND THE CONCEPT OF AN OBJECT–SUBJECT SPLIT WITH A WELL-DEFINED SUBJECT

In the process of the track formation in the Wilson-chamber detection of α-rays one has three important moments: t_α, when the α-ray is out of the nucleus, but has not yet interacted with the atoms in the chamber; t_a, when the α-rays have already interacted with Mott's double atoms, but the interaction between the double atoms and the saturated vapor has not yet set in and the tracks are not yet formed; and, finally, t_d, when the (beginnings of the) tracks of droplets have already been formed.

3.1. Some Tacit Elements in Mott's Theory

One should note that Mott's theory is mostly concerned with the moment t_a (and it is this moment that will be meant unless otherwise stated). I start my discussion of the theory of Mott by highlighting some elements that he mentions only superficially.

(i) In his *first case* (dealt with only qualitatively in the article) the double atoms in the chamber belong to the measuring instrument or the *subject* (a synonym that I find more appropriate in a theory of observation).

In each *individual* case of α-particle detection, one particular double atom becomes excited. Calling this act a *subject event* (for reasons that will become obvious further down), one has the feeling that it *occurs* in an objective way. We will have to establish the kind of this objectivity (see the last section).

(ii) In Mott's *second case* the atoms in the chamber are part of the quantum object. The subject begins with the droplets that later (when we go from t_a to t_d) will be condensed on the ionized atoms. This is a clear case of the *shift of the cut* between object and subject. It seems to be an example of Bohr's mentioned macroscopic complementarity principle. (That the atoms are not macroscopic, but microscopic systems is not so important. The more so, because Mott, for simplicity, has not considered all relevant atoms partaking in forming a macroscopic track.)

(iii) In his *second case* Mott has to consider the entire "object" (as contrasted to "subject") that he chose: this is the α-particle plus the double atom. There is now no reason why the α-rays alone (on their way from nucleus to the chamber) should be "particles." (It is this point that Mott does put explicitly.) But, the quantum theory that Mott tackles gives "rays" of three-particle (α-particle + double-atom) wave packets *coherently mixed* in a configuration-space analog of Gamow's one-particle spherical-wave solution. A more precise form of this "larger spherical wave" is given below [cf. (7)]. Mott speaks explicitly of the probabilities of the mentioned individual (three-particle) "rays" in the solution; but not of their *coherence*.

Thinking about this (a little more explicit) quantum mechanical picture of what is going on in the Wilson chamber, we cannot help wondering with Bell (1990) about the physical meaning of this "shifty split" (p. 36) between "system" and "apparatus" (i.e., object and subject), and about the possibility to move it. We ask ourselves if the α-rays are really particles before they reach the chamber, or are they waves as in the theory of Gamow. Further, we wonder if the mentioned three-particle rays are incoherently or coherently mixed before the droplets are formed.

We ask these questions as realists, expecting QM to give precise and unambiguous answers about what goes on in nature. And we are disappointed because QM does not seem to live up to our expectations. We wonder what has gone wrong, our feeling of realism or QM.

The relative-collapse interpretation of QM, which, as I am trying to show, is implicit in Mott's theory, yields natural answers to these questions along the lines of Bohr's ideas (see the last section). And, the way I see it, nothing has gone wrong, neither our feeling of realism nor QM. The only problem comes from some misconceptions in conventional QM.

A precise definition of a split will be useful for further clarifications in Mott's theory. It was given in previous work (Herbut 1993a,b).

3.2. The General Idea of a Split with a Well-Defined Subject

When a state vector or density matrix is given, we also know to what system it applies. This system is the *object* (of quantum mechanical description). We denote it by O. The rest of the universe is the *subject* S. Between object and subject there is an imaginary dividing line called a "cut" and denoted by /. In this case the subject is *ill defined* because it is completely empty of any information. Altogether, one is talking of a *split*, symbolically O/S, or, more precisely, of an *empty-subject split*.

To obtain a *split with a well-defined subject* from a given empty-subject split, one shifts the cut to enlarge the object (and to shrink the subject), and thus one obtains a new (empty-subject) split. Writing the previous split as $O/S \equiv 1/2$, where 1 and 2 denote the relevant subsystems, the new split is of the form

$$O/S \equiv (1 + 2)/\ldots \tag{1}$$

Further, the general state (density matrix) ρ_{12} (or the pure state $|\chi\rangle_{12}$) of the composite system 1+2 must be given. Then one defines an observable B_2 with a purely discrete spectral form

$$B_2 = \sum_k b^{(k)} Q_2^{(k)} \qquad (k \neq k' \Rightarrow b^{(k)} \neq b^{(k')}, \ \sum_k Q_2^{(k)} = 1) \tag{2}$$

on the second subsystem. The observable is called a *basic observable*, and those of its spectral events (projectors) $Q_2^{(k)}$ that have a positive probability in the given state ρ_{12} (or $|\chi\rangle_{12}$) are referred to as *subject events*. (Simple examples were discussed in the mentioned articles.)

Finally, one *shifts the cut* back to the left by joining subsystem 2 to the subject:

$$O/S \equiv (1 + 2)/\ldots \rightarrow O/S \equiv 1/2 \tag{3}$$

(Possible additional subsystems in the initial S, which are obviously irrelevant for the split with a well-defined subject, may be suppressed in the final S.) On account of the basic observable, the new split has a well-defined subject.

Having summed up the formal gear required for a sufficiently precise concept of an object–subject split with a well-defined subject (from previous work), we can return now to the two cases in Mott's theory, which are obtained from one another by shifting the cut. The presentation of Mott's theory will be simplified, aimed at bringing out only the basic point of this study: the *loss of coherence involved in the object–subject complementarity* (and its subjective nature).

Let us denote the α-particle as a subsystem by α, let the first layer of double atoms be denoted by a, and, finally, let the corresponding layer of saturated vapor (in which the beginning of the droplets will be formed) be subsystem d. (At the risk of oversimplifying the inessential, we can think of the Wilson chamber as a spherical layer with the nucleus at its center. Subsystem a is then the first double-atomic sublayer closest to the center, and subsystem d is a somewhat thicker layer of vapor permeating the layer a.)

3.3. Mott's Theory

To understand Mott's first case in sufficient detail, we start with the empty-subject split $O/S \equiv (\alpha + a)/(d + \ldots)$, and we define a suitable very simple basic observable:

$$B_a \equiv \sum_i (b^{(i,g)} Q_a^{(i,g)} + b^{(i,e)} Q_a^{(i,e)}) \tag{4}$$

which is appropriate in view of the state vector of the object that comes about as a result of the interaction between the α-ray and the double atom [see (7) below].

Here B_a is a simplified Hamiltonian, the index i enumerates the double atoms in the mentioned layer; $\forall i$: $b^{(i,g)}$ is the ground-state energy level of the ith double-atom system, $Q_a^{(i,g)}$ is the corresponding characteristic event (the occurrence of which means that the ith double atom is in the ground state, and the rest of the double atoms may be in any state); finally, $b^{(i,e)}$ is a (formal) single excited energy level of the ith double atom, and $Q_a^{(i,e)}$ is the corresponding characteristic event. (We have replaced the entire excited spectrum by one level because the details of the excitation do not matter for our discussion.)

Let Gamow's *spherical* wave that describes the α-particle at the moment t_α have the following simple form:

$$|\psi\rangle_\alpha \equiv \sum_i N^{-1/2}|\psi, i\rangle_\alpha \tag{5}$$

where the state vector $|\psi, i\rangle_\alpha$ describes a particlelike wave packet or "ray" directed at the ith double atom, and N is the number of atoms in the layer, i.e., the number of terms in (5).

The state vector $|\psi\rangle_\alpha$ describes a *coherent mixture* of (equally probable) "particle" states $|\psi, i\rangle_\alpha$. It expresses the wavelike property of the incoming α-ray in contrast to the latter state vector, which describes particlelike behavior.

On the other hand, let, at the same moment t_α, $|\phi\rangle_a^g$ be the initial state of the double-atom-layer subsystem, in which, by definition, all atoms are in the ground state, i.e., which satisfies

$$(\prod_i Q_a^{(i,g)})|\phi\rangle_a^g = |\phi\rangle_a^g \tag{6a}$$

After the interaction between the α-ray and the double-atomic layer has set in, at the moment t_a, let, $|\phi\rangle_a^{(i,e)}$ be the state vector of subsystem a in which, by definition, only the ith double atom is in the excited state and all the rest of the double atoms are in the ground state:

$$(Q_a^{(i,e)} \prod_{i' \neq i} Q_a^{(i',g)})|\phi\rangle_a^{(i,e)} = |\phi\rangle_a^{(i,e)} \tag{6b}$$

A simplified presentation of Mott's result about what happens as a consequence of the interaction between the α-particle and subsystem a, which we take to be instantaneous, is the transition of the initial state $|\psi\rangle_\alpha \otimes |\phi\rangle_a^g$ into

$$|\chi\rangle_{\alpha a} \equiv \sum_i N^{-1/2}|\psi, i\rangle_\alpha \otimes |\phi\rangle_a^{(i,e)} \tag{7}$$

This is the state vector that was called "rays of three-particle wave packets" (meaning $|\psi, i\rangle_\alpha \otimes |\phi\rangle_a^{(i,e)}$) "*coherently mixed* in a configuration-space analog of Gamow's one-particle spherical-wave solution" [the latter was given by (5)] or the "larger wave" as mentioned in the preceding section. Mott obtains (essentially) (7) as a solution of the characteristic equation of the Hamiltonian containing the relevant interaction.

The *state* ρ_α of *subsystem* α is, of course, to be described by *the reduced statistical operator* that is implied by (7):

$$\rho_\alpha \equiv \mathrm{Tr}_a(|\chi\rangle_{\alpha a}\langle\chi|_{\alpha a}) = \sum_i \sum_{i'} N^{-1}|\psi, i\rangle_\alpha\langle\psi, i'|_\alpha \, \mathrm{Tr}_a(|\phi\rangle_a^{(i)}\langle\phi|_a^{(i')})$$

$$\rho_\alpha = \sum_i N^{-1}|\psi, i\rangle_\alpha\langle\psi, i|_\alpha \tag{8}$$

because the state vectors $|\phi\rangle_a^{(i)}$ are orthonormal, i.e.,

$$\mathrm{Tr}_a|\phi\rangle_a^{(i)}\langle\phi|_a^{(i')} = \langle\phi^{(i')}|\phi^{(i)}\rangle_a = \delta_{i',i}$$

Following (3), we make the final shift of the cut

$$O/S \equiv (\alpha + a)/(d + \ldots) \rightarrow O/S \equiv \alpha/(a + d + \ldots)$$

to define a *split* (with a well-defined subject) of Mott's *first case*. Now we can discuss this case in more detail.

Since ρ_α given by (8) has the form of an *incoherent* quantum mixture, at first glance it may appear that we can now understand Mott's words "in this case we must consider the α-ray as a particle." The states $|\psi, i\rangle_\alpha$ can be viewed as "particle" states of the α-particle, and, so it may appear, each individual subsystem "α" is in one of these states.

Unfortunately, in conventional QM this view is *not consistent*. This is so because ρ_α does not describe a mixture, but a so-called *improper mixture* (D'Espagnat, 1976, Subsection 7.2). In short, the improper-mixture inconsistency argument goes as follows:

If an individual subsystem "α" were in the quantum mechanical state $|\psi, i\rangle_\alpha$, e.g., and the composite $(\alpha + a)$ system were in a state $\rho_{\alpha a}^{(i)}$ that determines $|\psi, i\rangle_\alpha$, namely $|\psi, i\rangle_\alpha\langle\psi, i|_\alpha = \mathrm{Tr}_a\rho_{\alpha a}^{(i)}$, then $\rho_{\alpha a}^{(i)}$ would necessarily differ from $|\chi\rangle_{\alpha a}\langle\chi|_{\alpha a}$ (because composite-system states determine the subsystem state uniquely, and $|\psi, i\rangle_\alpha\langle\psi, i|_\alpha$ is different from ρ_α). The state $|\chi\rangle_{\alpha a}$ is homogeneous, hence all its substates (describing subensembles) cannot be different from it. Thus, we have a contradiction.

How then can Mott speak of the states $|\psi, i\rangle_\alpha$ as individual α-particle states?!

Now we have pinned down what appears to be an inconsistency or *open problem* in Mott's theory if we apply rigid conventional QM. However, there is a way the above devastating argument can be avoided. Actually, Mott's theory itself offers a purely quantum mechanical solution as explained in Section 5.

There is another relevant question that must be raised. It is well known that a mixed state like ρ_α allows an infinite variety of decompositions into pure states (cf. Hadjisavvas, 1981). One wonders if the states $|\psi, i\rangle_\alpha$ that appear in decomposition (8), and which are relevant for Mott's theory, appear in a necessary way; in other words, if there is a physical reason for the privileged role of decomposition (8).

An affirmative answer is given in the split $O/S \equiv (\alpha + a)/(d + \ldots)$, and it goes as follows:

The state vector $|\psi, i\rangle_\alpha$ describes the *conditional state* of subsystem α under the condition that the *subject event* $(1 \otimes |\phi\rangle_a^{(i,e)}\langle\phi|_a^{(i,e)})$ *occurs in* the state $|\chi\rangle_{\alpha a}$ [given by (7)] of the composite system.

To see this in a simple way, let us assume that this event takes place in ideal measurement. Then $|\chi\rangle_{\alpha a}$ is converted into $|\psi, i\rangle_\alpha \otimes |\phi\rangle_a^{(i,e)}$. [One has to utilize the Lüders formula (Lüders, 1951; Messiah, 1961), which amounts to applying the projector of the event that occurs and normalizing the result.] Thus, the first subsystem is in the state $|\psi, i\rangle_\alpha$.

One can say that decomposition (8) is singled out (in the set of infinitely many possible ones) by the subject events that make up the basic observable B_a [cf. (4)]. In other words, the basic observable determines the decomposition of ρ_α. (And the relevant form of the latter makes the former suitably chosen.)

Returning to the simple physical meaning of the entities involved, one can state this insight as follows:

The individual α-particle is in the "particle" state $|\psi, i\rangle_\alpha$ if it interacts with the ith double atom and gives rise to its excitation. (This will be called "relative collapse" in Section 5.)

As to the second case of Mott, it corresponds to the moment t_a and the split $O/S \equiv (\alpha + a)/(d + \ldots)$. The split is now both well and ill defined. Namely, the further process, which will involve the formation of (the beginning of) a droplet, suggests that we define the basic observable accordingly [as in (9) below]. But also any other definition of the subject events gives $|\chi\rangle_{\alpha a}$ [cf. (7)] as the only conditional state. (The state being pure, it cannot be correlated or entangled with its surrounding. This is tantamount to the claim just made.)

The state of the composite $(\alpha + a)$ system is $|\chi\rangle_{\alpha a}$, the "larger spherical wave." There can be no talk of any particle states.

By a mere shift of the cut we have obtained an entirely different quantum mechanical situation, and the shift is a subjective act on our part. This suggests that we are dealing with some kind of relativity with respect to the choice of the split.

3.4. Mott's Theory Extended to Encompass the Tracks

Let us take the (empty-subject) split $O/S \equiv (\alpha + a + d)/\ldots$, and let us define the following *basic observable*:

$$C_d \equiv (\sum_i (c^{(i,g)}Q_d^{(i,g)} + c^{(i,e)}Q_d^{(i,e)})) \tag{9}$$

In analogy with the preceding basic observable B_a given by (4), $c^{(i,g)}$ and $c^{(i,e)}$ are the ground-state and the excited-state energy levels of the layer of saturated vapor where the ith (beginning of the) track of droplets is going to be formed; the occurrence of the event $Q_d^{(i,g)}$ means that the ith track is not formed, and that of $Q_d^{(i,e)}$ means that it has been formed.

Next, in analogy with (6a), (6b) in Mott's first case, we define the state $|\omega\rangle_d^g$, which is valid at the moment t_a, and the (beginning of the) track-of-droplets state $|\omega\rangle_d^{(i,e)}$, valid at t_d:

$$(\prod_i Q_d^{(i,g)})|\omega\rangle_d^g = |\omega\rangle_d^g \tag{10a}$$

$$(Q_d^{(i,e)} \prod_{i'\neq i} Q_d^{(i',g)})|\omega\rangle_d^{(i,e)} = |\omega\rangle_d^{(i,e)} \tag{10b}$$

In the present split we then go from the moment t_a, when we have the state $|\chi\rangle_{\alpha a} \otimes |\omega\rangle_d^g$, to the moment t_d and we envisage a composite three-subsystem state vector $|\chi\rangle_{\alpha ad}$, which comes about as a result of the interaction between the double-atom layer and the saturated vapor layer (putting it in a simplified way):

$$|\chi\rangle_{\alpha ad} \equiv \sum_i N^{-1/2}|\psi, i\rangle_\alpha \otimes |\phi\rangle_a^{(i,e)} \otimes |\omega\rangle_d^{(i,e)} \tag{11}$$

This implies the following state (reduced statistical operator) for subsystem $(\alpha + a)$:

$$\rho_{\alpha a} \equiv \mathrm{Tr}_d|\chi\rangle_{\alpha ad}\langle\chi|_{\alpha ad} = \sum_i N^{-1}|\psi, i\rangle_\alpha\langle\psi, i|_\alpha \otimes |\phi\rangle_a^{(i,e)}\langle\phi|_a^{(i,e)} \tag{12}$$

In conventional QM the reduced statistical operator $\rho_{\alpha a}$ describes an *improper mixture* of $(\alpha + a)$-subsystems. Hence, by an improper-mixture argument analogous to the one above, we conclude that $\rho_{\alpha a}$ applies (as a whole and indivisible state) to each *individual* α-particle + (double atom), i.e., that one cannot say that a term in (12), say $|\psi, i\rangle_\alpha \otimes |\Phi\rangle_a^{(i,e)}$, is the actual state of this system.

Hence, apparently, we are again unable to reproduce Mott's idea that the individual $(\alpha + a)$-subsystem is in a state $|\psi, i\rangle_\alpha \otimes |\Phi\rangle_a^{(i,e)}$. What is missing is the idea of *collapse*, which would reduce $|\chi\rangle_{\alpha ad}$ to one of the terms in (11) as far as an individual (composite) system is concerned.

It is clear that collapse cannot appear by just shifting the cut to the right, because this would only enlarge the composite system that should collapse. One wonders if there is any conceivable way to obtain collapse without taking resort to some extra-quantum-mechanical agency.

The basic question is whether one should think about collapse as an absolute, i.e., observer-independent, process (that goes on in nature), as many well-known interpretations of QM do, or one should rather take it as a relative appearance (that depends on the split between object and subject). Our detailed analysis of the proper Mott theory (at the moment t_a) and the short analogous analysis of Mott's extended case (at t_d) suggest that we should decide on the second alternative.

4. WHAT ABOUT THE COLLAPSE AND THE CORRESPONDING LOSS OF COHERENCE?

There is a psychological complementarity between detail and the whole. (Watching the trees, you do not see the wood.) Let us try to recover the whole in Mott's theory made explicit.

Let us start by summing up the *tacit elements* of Mott's theory discussed in the preceding section.

One has a *shiftable* (or displaceable) *cut* between *object* and *subject.* The subject has to be *well defined.* This is achieved in terms of a *basic observable* (with a purely discrete spectrum), which is defined on a subsystem belonging to the subject in an appropriate way characteristic for the measurement process. In a given state, the positive-probability characteristic events of the basic observable, the so-called *subject events,* play a decisive role in the *loss of coherence* because they *occur* in the individual measurements in Mott's theory in spite of the *coherence* that is present in the composite-system states [in $|\chi\rangle_{\alpha a}$ given by (7) in Mott's theory or in $|\chi\rangle_{\alpha ad}$ given by (11) in Mott's extended theory].

Since we are concerned with the question of interpretation of QM, and this is based, naturally, on a theory of quantum measurement, the mentioned collapse and the corresponding loss of coherence in the larger system constitute for us the most important point in the theory.

It is very easy to get mixed up because there are two "losses of coherence," one due to the (linear) dynamical law, and the other due to observation.

Taking into account all the subsystems involved in the (part of the) cloud chamber (that is considered), i.e., the α-particle, the double-atom layer, and the corresponding layer of vapor, and assuming that we have thus a dynamically isolated system, the characteristic vector, solution of the characteristic equation of the Hamiltonian (with all relevant interactions included), is the "largest spherical wave" $|\chi\rangle_{\alpha a d}$ given by (11). [The corresponding split is $O/S \equiv (\alpha + a + d)/\ldots$ with an ill-defined subject.]

Thus, the interaction between the α-particle, the double-atom layer, and the layer of vapor *displaces* the original coherence in the spherical wave $|\psi\rangle_\alpha$ [given by (5)] from the α-particle (when it was a free particle, before the interaction began) to the composite system $(\alpha + a + d)$.

This displacement of coherence "from local to global" (Joos and Zeh, 1985) is a basic trait of the linear dynamical law. [This was well understood already by von Neumann (1955).]

In each of the proper subsystems we have loss of coherence. But in the largest (dynamically isolated) system the coherence is preserved.

We are interested in the *second loss of coherence*, the one that comes about in *observation*. Taking the split $O/S \equiv (\alpha + a)/d$ (as in Mott's second case) or the split $O/S \equiv \alpha/(a + d)$ (as in Mott's first case), a *well-defined subject* is introduced and thus *observation* is taking place.

It seems to be a tricky point that, at first glance, there is no new loss of coherence, only the first one due to the dynamics. Namely, treating the subject classically, it displays no coherence. But, as was pointed out, the subject, as a subsystem of a composite system, did not have coherence anyway. Similarly, the object displays no coherence, but for the mentioned dynamical reasons, this is as it should be.

The *second loss of coherence* does not take place in any subsystem, it comes about *in the entire* (dynamically isolated) $(\alpha + a)$ or $(\alpha + a + d)$ composite system (in Mott's theory and in its extension, respectively). *In observation one disregards the coherence therein.* How can one do this?!

Well, one must take the given split seriously. For instance, in Mott's first case, the *object* is only the α-way (without the double-atom layer, etc.). Hence, the argument that established ρ_α given by (8) to be an improper mixture due to the existence of the composite state $|\chi\rangle_{\alpha a}$ given by (7) simply does not go through, because the state $|\chi\rangle_{\alpha a}$ is meaningless in this split: One cannot combine object and subject to make a state (unless one shifts the cut, but this is then another split).

Analogously, once the split $S/O \equiv (\alpha + a)/d$ of Mott's second case is fixed, the coherent state $|\chi\rangle_{\alpha a d}$ of the entire system [given by (11) in the extended theory] does not make sense, and hence the reduced statistical operator $\rho_{\alpha a}$ [given by (12)] does not describe an improper mixture.

Thus, the given splits make Mott's individual-system collapses quite legitimate (or consistent).

By this one should not be confused by the shiftings of the cuts that were performed when the splits with well-defined subjects were constructed. A ready and fixed split of this kind is what makes a given observation well defined.

All this can be put in a more explicit and sharper form. We do this in the next section.

5. THE OBJECT–SUBJECT COMPLEMENTARITY PRINCIPLE AND THE RELATIVE-COLLAPSE POSTULATE

Let us bring the main ideas that emerged in the above discussion of Mott's theory into focus.

Converting a part of the object into a part of the subject is, obviously, the essence of what Shimony calls "Bohr's macroscopic complementarity principle." We have completed it with the notion of a split with a well-defined subject.

But this is only the appropriate framework. The essential point is what was called in the preceding section "*the second loss of coherence*." Let us give it in full detail.

Once the well-defined subject is specified, the possible coherence in the entire composite (object plus subject) system is lost. This second loss of coherence is *relative* with respect to the chosen split. What appears in the place of the coherence must be expressed on two levels:

(A) *On the individual-system level* one of the subject events *occurs* (this is the essential part of the definition of observation), and then, as a necessary quantum mechanical (or mathematical) consequence, the object state *collapses* into what was previously the corresponding *conditional state* (the "particle state" $|\psi, i\rangle_\alpha$ in Mott's first case or the composite particle state $|\psi, i\rangle_\alpha |\phi\rangle_a^{(i,e)}$ in the second extended Mott case). I call this *relative collapse*, and the very assumption of the occurrence of the subject event that gives rise to the collapse I call *the relative-collapse (RC) postulate*.

(B) *On the ensemble level* the *Born postulate* is in action: the relative frequencies of the occurrences of the subject events (and of the accompanying relative collapses mentioned in A) are given by the quantum mechanical prediction, i.e., by the probability for the subject event in question in the composite-system state (valid when the subject has become part of the object by shifting the cut). Both in Mott's proper theory and in his extended one this probability is uniform (over the values of i) and equals $1/N$.

As is well understood by now, what we call historically Born's postulate is actually a consequence of a theorem due to Gleason (1957). The latter tells us, essentially, that in Hilbert space there is only one way to obtain probabilities, and this is by using the quantum mechanical formula.

Altogether, we have elaborated Bohr's macroscopic complementarity principle into what I call the *object–subject complementarity principle*.

The *complementarity* shows up in the fact that each of the two versions of observation (e.g., the double-atom subsystem part of the subject or part of the object, respectively) has an advantage and a disadvantage: When, e.g., this subsystem in Mott's theory is part of the subject, each individual α-ray has a definite trajectory (an advantage), but only the subsystem α is the object of quantum mechanical description (a disadvantage). When the double atom is part of the object, a more complex system ($\alpha + a$) is described by QM (an advantage), but this system is given by the "larger wave" (7) for *each individual system*, i.e., the latter cannot be told apart (a disadvantage). (We take up this complementarity principle again in the last section.)

For more clarity, a few remarks are desirable.

(a) The occurrence of the subject event is *objective* in the proper quantum mechanical sense, i.e., any (immediately) subsequent measurement of the subject event (or of the basic observable) *on the individual system at issue* in the existing state of the composite (object-plus-subject) system necessarily confirms its occurrence. (This corresponds to the well-known objectivity of the individual track in the Wilson chamber.)

(b) Occurrence of the subject event has the special-relativistic covariance required by its objectivity. [This can be seen in a simplified way along the lines of Dieks' (1985) article.]

6. COMPARISON WITH THE MANY-WORLDS AND THE MODAL INTERPRETATIONS

There are two interpretations of QM that stand in some respects close to the relative-collapse interpretation proposed in this article.

The first is Everett's (1957) theory. Also this interpretation preserves the coherence in the "larger" (or in the "largest") composite system (depending on the example we take), and in spite of this it tries to achieve what is tantamount to collapse. In two recent articles Broyles (1992, 1993) introduced Everett's theory into the theory of Mott (1929). (For lack of space, I will not comment on them in this article.)

The second interpretation is the modal one of Dieks (1993, 1994) and of others [see, e.g., the references in Dieks (1994)]. Also this theory claims that the coherence in the largest system is preserved.

6.1. The Many-Worlds Interpretation

The rather popular *Everett theory* (Everett, 1957) introduced "relative states" in the same way as this article, though only in a restricted way: for basic observables with a simple spectrum, when the use of the subject events amounts to expansion of the composite-system state vector in a subsystem basis.

Then Everett, so it seems to me, erroneously concluded that, calling distinct subject events $Q_2^{(k)} = |\phi, k\rangle_2\langle\phi, k|_2$ [cf. (2)] and the corresponding relative states $\rho_1^{(k)} = |\psi, k\rangle_1\langle\psi, k|_1$ of the object "branches" (or separate "worlds"), the very dynamical law will necessarily keep them apart. At least this is how I understand his comment (cf. his "Note added in proof," pp. 459, 460): "all the separate elements of a superposition [cf., e.g., (7) above] individually obey the wave equation with complete indifference to the presence or absence ('actuality' or not) of any other elements."

He seemed to think that he derived in this way what he called "falling into one of the branches or worlds" (having in mind an individual system). This is tantamount to collapse.

This claim of Everett, of course, contradicts that of numerous other authors who realized [beginning with von Neumann (1955)] that absolute collapse cannot be derived from the quantum mechanical (linear) dynamical law. Everett's mistake was clearly pointed out by Moldauer (1972), and it was implicit already in Furry's (1936) article.

Taking this fact into account, I cannot help thinking of a consistent version of Everett's theory as of one that imposes the falling-into-one-branch as a *postulate*. But this is tantamount to introducing absolute collapse in a verbal (and somewhat mystical) way [cf. Shimony (1963), who seems to have a similar impression of Everett].

I think that the most devastating (known) argument against the many-worlds interpretation is pointing out the fact that the very branching (or division into worlds) is not well defined mathematically. Namely, one can expand a given composite-system state vector in an uncountable infinity of ways in some one-subsystem orthonormal basis. The (unique) expansion coefficients are the relative states of the complementary subsystem. I could never understand if Everett thinks of all these branchings taking place simultaneously (a nightmare!), or whether one is singled out. But which one?! One cannot tell without an extra-quantum-mechanical agency defining the measuring instruments, e.g. But then we are not dealing with a purely quantum mechanical theory.

It is my feeling that the modal interpretation is a reaction precisely to this kind of criticism of Everett's theory. It seems to sidestep it successfully.

One can raise also the mixed-state criticism against the many-worlds approach. It is given below [Section 6.2, item (ii)].

I would like to comment on a sentence from Squires' (1990) very inspiring Rome talk. Putting it freely, it ran as follows:

"In Everett's theory *nothing happens*; the world just evolves, and evolves."

Squires obviously did not accept Everett's "branching" of the universe either as a postulate or as an (erroneous) consequence of dynamical evolution (or else the very falling into one branch would be the "happening" required). I disagree that nothing happens.

What *does "happen"* (in a sense) all the time (and continuously at that) is the *creation of quantum correlations* (or entanglement) between any two subsystems on account of interaction. And this corresponds to reality in an objective and unambiguous way.

But (and now I switch over to relative-collapse QM, which seems to me to be the missing thing in Everett's theory) to "read" the correlations, one must take resort to an arbitrary one of a number of possibilities (as often is the case in physics): one must decide on a split *O/S* with a well-defined subject. And this can be chosen in different ways, and one can, by shifting, go from one to another. (Though there are also incompatible ones which cannot be reached from each other by shifting the cut. This is the case when we have two incompatible basic observables. They are then on the same subsystem of course.)

Everett's theory is a useful interpolation between the classical theories (see Section 2) and a more consistent theory as attempted in this article, because it introduces correctly the "relative state" concept (though failing to realize its full specific quantum mechanical "relativistic" significance).

6.2. The Modal Interpretation

The modal interpretation deals with the state vector of a (sufficiently large) composite system. It postulates that (any) one of the characteristic projectors of the reduced statistical operator of a subsystem that corresponds to a positive characteristic value expresses a sharp *individual system property.* [These projectors determine the unique features of the Schmidt canonical form (Herbut and Vujičić, 1976).]

The modal interpretation has no subject belonging to QM itself. It addresses reality directly, treating any two complementary subsystems of the mentioned composite system on an equal footing.

The modal interpretation, if I understand it correctly, would not accept Mott's composite-systems states $|\chi\rangle_{\alpha a}$ [given by (7)] and $|\chi\rangle_{\alpha ad}$ [given by (11)] at their face value. It first would have to explain away somehow the homogeneity over i. (This seems to be a serious shortcoming to me.)

If $(1/N)^{1/2}$ could be replaced by some *distinct* square-root probabilities $w_i^{1/2}$, e.g. [in both (7) and (11)], then this approach could accept the state vectors thus modified with all the coherence in them, and it would claim that, in Mott's first case, e.g., the individual α-ray *has one of the properties* $|\psi, i\rangle_\alpha\langle\psi, i|_\alpha$ [cf. (7)], *but not that it is in the state* $|\psi, i\rangle_\alpha$. In this way it sidesteps the improper-mixture argument against interpreting ρ_α and $\rho_{\alpha a}$ as actual mixtures [cf. (8) and beneath it, and (12)].

My further comments are:

(i) Endowing the individual α-ray in Mott's first case with the property $|\psi, i\rangle_\alpha\langle\psi, i|_\alpha$ does seem to explain how one gets an individual-system measurement result in spite of the coherence in the modified $|\chi\rangle_{\alpha a}$, but it does not explain how an immediately succeeding measurement of *any* observable A_α on the same individual α-ray (which is not done in the Wilson chamber), when raised to the ensemble level, gives the quantum mechanical expectation value $\langle\psi, i|A_\alpha|\psi, i\rangle_\alpha$. (This is, of course, the same as saying that the α-ray *is* in the state $|\psi, i\rangle_\alpha$).

(ii) The typical laboratory state is a mixture, not a pure state (which is often not so easy to achieve). I would expect that it would be much harder to formulate the modal interpretation in terms of general (i.e., mixed or pure) states.

My reason for this expectation is the fact that the interpretation at issue is based on the Schmidt canonical or biorthogonal form of a *state vector* (Herbut and Vujičić, 1976; see also von Neumann, 1955; Schrödinger, 1935). [Relations (7) and (11) are examples of it.] To my knowledge, no corresponding canonical form (with very nice properties) exists for entangled mixed states of composite systems.

To illustrate this comment in a more intuitive way, we take the simple mixed state

$$\rho_{12} \equiv w|\psi\rangle_1\langle\psi|_1 \otimes |\phi\rangle_2\langle\phi|_2 + (1-w)|\psi\rangle'_1\langle\psi|'_1 \otimes |\phi\rangle'_2\langle\phi|'_2 \quad (0 < w < 1)$$

$$|\psi\rangle_1 \neq |\psi\rangle'_1, \qquad |\phi\rangle_2 \neq |\phi\rangle'_2$$

If one could say that the composite (1 + 2) system is with probability w in the state $|\psi\rangle_1\langle\psi|_1 \otimes |\phi\rangle_2\langle\phi|_2$ and with probability $1 - w$ is in the state given in the second term, then the modal interpretation, the way I see it, would claim that the individual first subsystem has with probability w the property $|\psi\rangle_1\langle\psi|_1$ and with probability $1 - w$ the property $|\psi\rangle'_1\langle\psi|'_1$.

The trouble is that the same state ρ_{12} has an uncountable infinity of different decompositions into pure states (Hadjisavvas, 1981), and they are all physically equally valid. Thus the above simple so-called ignorance interpretation does not go through, and we seem to be left with an (uncountably infinite) nightmare of possibilities for the sharp properties of the individual subsystems.

As mentioned above, also the Everett interpretation does not seem conceptually equipped to deal with mixed states.

For lack of space I will show elsewhere that the relative-collapse interpretation of QM is almost as simple for a mixture as for a pure state. (The biorthogonal form of Mott's composite-system pure states, though typical in pure-state measurement theory, is not essential.)

(iii) Though undoubtedly it is very appealing to address reality directly, without an intermediary (i.e., without the notion of a subject), as is done in the modal interpretation, there are reasons to doubt that it can be satisfactorily performed.

The choice of a subject bears some resemblance to that of a coordinate system when the position of a particle is to be specified. When going to a different frame, the position of the previous zero point relative to the new frame has to be given. This runs parallel to our shifting the cut to enlarge the object. Then that part of the previous subject which has become part of the new object must be incorporated into the state of the new (entire) object.

As is well known, one cannot express the points of space directly, without an intermediary (a frame of reference). It is my conjecture that also the analogous statement is true: QM cannot describe reality (in a complete and consistent way) unless it makes use of an intermediary (of a subject as part of a split).

The way I see it, this dilemma (without or with a subject) goes back to the famous controversy between Einstein and Bohr (see Jammer, 1974). The former believed in real properties of quantum mechanical objects that are then statistically correlated (in entangled states), whereas Bohr seemed to believe that quantum correlations are more primitive or basic than properties, and the latter are only secondary products coming out of the correlations in QM. (He often insisted that the object–subject relation cannot be thought of as disentangled in nature. To my understanding this is a negation of Einstein's position.)

If Bohr is right, then one has to "read" the correlations by choosing a split with a well-defined subject (or one must specify the classical measuring instruments in terms of which the properties are to be determined in the laboratory, as Bohr would say). Then quantum mechanical properties of physical objects can surface.

Let me close this comparison by emphasizing an important feature that the relative-collapse, the modal, and the many-worlds interpretations of QM do have in common: it is the assumption that the coherence in the state of the largest system is preserved. In the RC approach of this article, in contrast to the other two theories, the coherence is valid only in a split in which the largest system is the object, e.g., in $O/S \equiv (\alpha + a + d)/\ldots$ But this makes it no less real (see the end of the next section).

To my knowledge, all other interpretations have two important features: the collapse is an absolute quantum mechanical process, and it is due to some extra-quantum-mechanical agency.

The coherence in the state of the largest system can be *experimentally verified*. In the example of $|\chi\rangle_{\alpha a d}$ given by (11), one has to measure the coincidence of three one-subsystem observables A'_α, B'_a, and C'_d, each of which is *incompatible* with all the corresponding component states:

$$\forall i:\quad [A'_\alpha, |\psi, i\rangle_\alpha\langle\psi, i|_\alpha] \neq 0, \quad [B'_a, |\phi\rangle_a^{(i,e)}\langle\phi|_a^{(i,e)}] \neq 0,$$

$$\text{and}\quad [C'_d, |\omega\rangle_d^{(i,e)}\langle\omega|_d^{(i,e)}] \neq 0$$

By a suitable choice of the observables at issue, the probabilities of the coincidences will differ from the corresponding ones evaluated in the corresponding incoherent mixture

$$\rho_{\alpha ad} \equiv \sum_i N^{-1}|\psi, i\rangle_\alpha\langle\psi, i|_\alpha \otimes |\phi\rangle_a^{(i,e)}\langle\phi|_a^{(i,e)} \otimes |\omega\rangle_d^{(i,e)}\langle\omega|_d^{(i,e)}$$

7. CONCLUDING REMARKS

In previous work (Herbut, 1993a,b) the Stern–Gerlach measurement was sketchily discussed (with a shiftable split, but without the relative-collapse postulate). The point to note is that there is an "isomorphism" between the cloud-chamber and Stern–Gerlach measurements: to the α-ray position corresponds the spin projection, the counterpart of the double-atomic layer is the spatial (tensor-factor) state expressing upward or downward motion, and finally, the analog of the tracks of droplets are the dots formed on the upper and lower plates of the screen. Thus, the relative-collapse view of the Wilson-chamber measurement can be transferred directly to the Stern–Gerlach measurement.

A preliminary version of the present approach to interpreting QM has presented in a short communication (Herbut, 1990).

Let us return to the questions that we posed at the end of our discussion of Mott's original theory (end of Section 3.1), and let us try to give answers in the spirit of the proposed relative-collapse QM.

As to Mott's "rays" [either of α-particles or of three-particle systems $(\alpha + a)$], we can say that the question whether these are "particles" or "waves," i.e., if we have incoherent or coherent mixtures, is not a question about observer-independent reality; it is a question that can be rightfully posed when a split with a well-defined subject is already defined. Or, to return to Bohr's well-known words, "the *measuring instruments* which serve to define, in classical terms, the conditions under which the phenomena appear" are required (Section 2).

Bohr sticks to classical measuring instruments as subjects. But the latter are an extra-quantum-mechanical agency. In this article a purely quantum mechanical approach is developed, and therefore the "classical" instruments are generalized into a well-defined subject.

The above "particles" or "waves" are, of course, Bohr's "phenomena," which cannot "appear" unless the "measuring instruments" (which define the split with a well-defined subject) are specified.

The spurious nature of the question of whether we are dealing with "particles" or "waves" in reality bears some resemblance to the classroom question on the Schrödinger and the Heisenberg dynamical pictures (or representations): "What does in reality change, the state or the observables?" The well-known answer, of course, is that change of one (or both) of the mentioned entities does not describe "reality" in a picture-independent way; it is the entirety of the formalism that matters, and its physical content is invariant under the choice of the picture. It is similar in relative-collapse QM (where the quantum correlations or entanglement are the counterpart of the mentioned "entirety").

To sum up, in the suggested interpretation of QM, which we call relative-collapse QM, absolute or observer-independent *reality* captured by quantum mechanical description consists in the *quantum correlations* between the subsystems. The *phenomena*, no matter how basic they appear to us classically trained beings, are "real" no sooner than the observer is specified. Their reality is *relative*. This is quantum mechanical relativity.

Thus, "the second loss of coherence," which was said to be the most important point for us in Mott's theory (Section 4), is a *relative* affair. Taking the split $O/S \equiv (\alpha + a + d)/\ldots$, e.g. (though with an ill-defined subject), one has coherence, i.e., wavelike behavior of the "largest" system. But if one takes any of the two splits in which the cut is moved one or two places to the left (as in Mott's second and first cases, respectively), one deals with an entirely different observation, and there is no coherence relative to the subject in question.

The point to notice is that, as in any kind of relativity theory, all splits are physically equally good, and one cannot do without one. (Even preparation, this is how the story usually begins, establishes a split. This will be discussed in detail elsewhere.) Hence, quantum mechanical reality must be expressed in the way a subject (or an observer) sees an object. Realism is primarily concerned with observer-independent statements. We must look for this in the quantum correlations (or entanglement) between subsystems.

I imagine that a convinced *positivist* might accept the relative-collapse interpretation, and would not be bothered by the impression that it appears somewhat formal. The *realist*, however, might be repelled by the apparently formal nature of the suggested postulate. I offer the following physical picture.

Quantum mechanics is considered *incomplete* (cf. Herbut 1991): there are essential parts of reality that QM cannot encompass in one unified realistic picture (unlike the attempts in the modal interpretation, e.g.). In other words, QM cannot describe *simultaneously* all these parts. But none of these parts is necessarily outside QM.

One can understand this through the short-blanket situation: the sleeper may cover his head, then his feet are bare; alternatively, he may cover his feet, then his head is left uncovered.

We consider now the "largest" system ($\alpha + a + d$) with all relevant interactions included, and in the split $(\alpha + a + d)/\ldots$ at that. Then *all* statistical predictions concerning the system ($\alpha + a + d$) (and all its subsystems of course) are given by the state vector $|\chi\rangle_{\alpha a d}$ [cf. (11)], and *correctly* I believe. In other words, the coherence in the state vector is real in this observation. (The head is covered in our analogy.) But the same state vector describes all individual composite systems; there is nothing in the quantum mechanical formalism to tell them apart. (The feet are bare.)

On the other hand, in this same dynamical situation if we take the split $(\alpha + a)/d$ [with a well-defined subject based on the basic observable C_d given by (9)], then $\rho_{\alpha a}$ given by (12) describes the entire object. It is not an improper mixture; it is a true mixture in which precisely the states $|\psi, i\rangle_\alpha \otimes |\phi\rangle_a^{(i,e)}$ (they are the conditional or relative states determined by the mentioned basic observable) are mixed. In other words, an ignorance interpretation can now be applied saying that each individual ($\alpha + a$) system is in one of the states $|\psi, i\rangle_\alpha \otimes |\phi\rangle_a^{(i,e)}$ (with the probability $1/N$).

Coming back to our short-blanket analogy, in the $(\alpha + a)/d$ case of observation at the moment t_d the subsystem d and the correlations between the subsystems ($\alpha + a$) and d are not described. This is a shortcoming of this observation. (The head is uncovered in our analogy.) But each individual ($\alpha + a$) system does have a value of i, i.e., one double atom is hit and the corresponding beginning of a track of droplets is formed. (The feet are covered.)

The two observations, differing from each other by the choice of whether the subsystem d is part of the object or of the subject, each has an advantage and a shortcoming. This is what is meant by the object–subject complementarity principle. (It actually incudes the relative-collapse postulate.)

Thus, from the realist's point of view nature is richer than QM. In nature any observable on the entire system ($\alpha + a + d$) can be measured and, simultaneously, to each individual ($\alpha + a + d$) system there corresponds a definite track. But QM, so the relative-collapse interpretation says, must define an observation (i.e., a split with a well-defined subject), and then it can at once describe only one of the two mentioned parts of nature.

In the mentioned previous article (Herbut, 1991), Bell's (1987) *beables* were used for a realization of such a "short-blanket" realistic physical picture.

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