god's abacus' are not strung on a single rod, but are pierced by many entangled strings.

Ergo:

1. "God does not play dice", but only possesses finite information.

2. The 'Holographic principle' — all physical information in the causality-connected world has a finite measure and is conserved according to this measure.

3. Information is most likely available to god as a graph (matrix) of 'real' distances (relations) between elementary identifiers, or between distinct states of the world as a whole. The measure of action with respect to path is responsible for the distinction of states. This picture is compatible with Feynman diagrams, because probabilities, amplitudes and representations of Lee groups are all exponentials of action, while information is linked with action directly after taking the logarithm of these exponentials. In order to make information finite without the arbitrary component, one should try using a particular (half)-integer action.

In support we give an amorphous list of references which contain not too transparent analogies [11 – 14]. The transformation of a pure state into a density matrix in the measurement procedure is described by Zurek in Ref. [5], and presented in Ref. [6]. The conclusion of conservation of information follows if every time both the measuring device and the observer are included in the closed physical system concealed within the general unitary evolution operator — it is important that the information should not be pulled out or pushed in. The ways of a quantum system are inscrutable — God cannot gain more knowledge (after all, we also are in His hands).

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On the problem of selection of an alternative in quantum measurement

A D Panov

Two new closely related directions in quantum theory are currently actively being developed: quantum informatics and the theory of decoherence. A number of basic notions pertaining to this domain may be regarded today as well established. A sufficiently popular introduction without unnecessary simplification is given in the first three sections of the paper by M B Menskiĭ [1]. The fourth section deals with the role of the observer's consciousness in quantum measurement, and in our opinion is rather controversial.

The problem as we see it is the following. One can attempt to describe the process of measurement solely on the basis of unitary evolution in accordance with the Schrödinger equation, as first proposed by Everett [2]. Consistent application of the Schrödinger equation to a closed system that includes the studied microscopic object and its macroscopic environment (equipment, etc.) leads to a superposition of macroscopically distinct states describing the alternative outcomes of the measurement. The learned author notes that such a description does not provide for the mechanism of selection of any one alternative. Since in a real experiment the observer will only deal with a single alternative, such description of measurement is viewed as incomplete: it lacks the mechanism of selection of the alternative. Further on, the author claims that a theory that would describe such a mechanism must necessarily involve the consciousness, and proposes including the consciousness into the theory as the element that would logically complete the quantum description of measurement. Consciousness is charged with the *function* of selection of one of the alternatives from the coherent superposition of various possible outcomes of measurement, thus reconciling theoretical predictions and experimental results. As far as we understand, this implies that the consciousness is factored out from the framework of dynamic description, and appears as an explicit *metatheoretical element* for interpretation of the theory. There exists, however, a different view on the role and place of consciousness in quantum measurement, and fully acknowledging the importance of this issue we feel obliged to present it in this letter.

There are a number of works that give a consistent quantum treatment of the selection of an alternative by the consciousness of the observer in a quantum measurement. For example, the pivotal issue in the classical work of Everett [2] is the express inclusion of consciousness into the quantum description. Moreover, Everett maintains that such a descrip-

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tion *predicts* that the consciousness of the observer *must* perform the selection of one alternative. The contemporary view of this topic can be found in the paper by Zeh [3] (see also the references therein). Let us show how the selection of the alternative by consciousness in quantum measurement can be described strictly within the framework of unitary quantum evolution.

Consider a system consisting of the following four parts: S — the measured microsystem; D — the measuring device (which may also include all communication channels as necessary for conveying the information to the observer's consciousness); M — the consciousness or mind of the observer; and E — the macroscopic environment (which may include an arbitrarily large fragment of the Universe, *but not the entire remaining Universe*). We assume that the composite system $U = S \otimes D \otimes M \otimes E$ is isolated and performs unitary evolution in time. Let the initial state of the system S before the measurement be

$$|\Psi_0\rangle = (\alpha|S_a\rangle + \beta|S_b\rangle)|D_0\rangle|M_0\rangle|E_0\rangle\,,$$

where $|D_0\rangle$, $|M_0\rangle$, $|E_0\rangle$ are the states of the device, consciousness and environment before the measurement, and the states of the microsystem $|S_a\rangle$ and $|S_b\rangle$ are mutually orthogonal. For the sake of simplicity we assume that the microsystem only interacts with the device, the device interacts only with the observer's consciousness, and the observer's consciousness interacts with the environment. We also assume that all the interactions work as nondestructive (nondemolishing) measurements.

The process of measurement can be represented as three consecutive steps. The first step is the interaction of the microsystem with the device, which leads to a correlation between the reading of the instrument and the state of the microsystem:

$$(\alpha|S_a\rangle + \beta|S_b\rangle)|D_0\rangle|M_0\rangle|E_0\rangle \rightarrow (\alpha|S_a\rangle|D_a\rangle + \beta|S_b\rangle|D_b\rangle)|M_0\rangle|E_0\rangle\,. \tag{1}$$

Here $|D_a\rangle$ and $|D_b\rangle$ are the readings of the device corresponding to states $|S_a\rangle$ and $|S_b\rangle$ of the microsystem. The second step is the interaction of the device with the observer's consciousness, which leads to a correlation of the state of consciousness and the reading:

$$(\alpha|S_a\rangle|D_a\rangle + \beta|S_b\rangle|D_b\rangle)|M_0\rangle|E_0\rangle \rightarrow (\alpha|S_a\rangle|D_a\rangle|M_a\rangle + \beta|S_b\rangle|D_b\rangle|M_b\rangle)|E_0\rangle\,. \tag{2}$$

The third step is the interaction of the observer's consciousness with the environment, which leads to a correlation of the state of consciousness and the environment:

$$(\alpha|S_a\rangle|D_a\rangle|M_a\rangle + \beta|S_b\rangle|D_b\rangle|M_b\rangle)|E_0\rangle \rightarrow (\alpha|S_a\rangle|D_a\rangle|M_a\rangle|E_a\rangle + \beta|S_b\rangle|D_b\rangle|M_b\rangle|E_b\rangle)\,. \tag{3}$$

This step is important, because it is here that the classical nature of consciousness is manifested. The state of consciousness as a classical object will show rapid decoherence because of interaction with the environment.

The observer will directly perceive only his own subjective sensations — that is, the state of his consciousness. Therefore, the subjective sensations of the observer are defined by the reduced density matrix of his consciousness, which follows from the total function of state of the composite system after averaging over the degrees of freedom that are external with respect to consciousness. After Step (1) the state of consciousness obviously remains the same as before. After Step (2) the consciousness is no longer described by the unique vector of state. Assuming that $\langle D_a|D_b\rangle \cong 0$ for the distinct macrostates, from the right-hand side of Eqn (2) it is easy to find the reduced density matrix of the observer's consciousness:

$$\rho_M^{(2)} = |\alpha|^2|M_a\rangle\langle M_a| + |\beta|^2|M_b\rangle\langle M_b|\,. \tag{4}$$

The state of consciousness exhibits decoherence because of the correlations between the states of the instrument and the states of the consciousness. Assuming that $\langle E_a|E_b\rangle \cong 0$, from the right-hand of Eqn (3) it is easy to find the state of consciousness after the third step of evolution; it is easy to prove that $\rho_M^{(3)} = \rho_M^{(2)}$. Step (3) does not change anything in the consciousness of the observer — all important changes have already occurred in Step (2).

The state of consciousness (4) must be interpreted as follows. Since $|M_a\rangle$ and $|M_b\rangle$ are classical macrostates, State (4) is a completely decoherent classical distribution of probabilities, like $\rho(p,q)$ in statistical mechanics. This in its turn implies firstly that the system M occurs in one and only one of the two classical states, and secondly that the probabilities of coming to these states are, respectively, $|\alpha|^2$ and $|\beta|^2$, as predicted by the projection postulate. Just as in statistical mechanics there is no problem of selection of one of the classical states (p,q) for the state defined by the distribution $\rho(p,q)$, here we have no problem of selection of the state of consciousness. The observer perceives himself in one of the classical states: either $|M_a\rangle$ or $|M_b\rangle$ — that is, the choice has been made. The existence of the distribution function only means that it is not possible to say in advance in which state the consciousness is going to end. Moreover, following Everett one may state that the formalism *predicts* — at the moment of nascency of correlations of the states of instrument and consciousness the observer subjectively performs the selection of the alternative. Observe that the exact Schrödinger equation gives a nonselective description of evolution, so one cannot demand a more detailed description of the selection of one of the alternatives: there simply is no appropriate language for that.

In this way, the selection of the observer is completely described within the framework of unitary evolution. In spite of the fact that the entire composite system U performs unitary evolution and does not take any choices, the consciousness of the observer does make a choice, and the *mechanism of making such choice is described expressly*.

It may seem that this approach may lead to the final solution of the problem of quantum measurement. In our opinion, however, this is not the case. The solution of the problem of measurement is indeed given within the framework of the above *model*, but the model itself is in certain respects not consistent. We regarded the composite system U as an isolated system that performs unitary evolution, which actually cannot be even approximately true for a macroscopic system of this type. The environment E, being macroscopic and classical, will exhibit very rapid decoherence through interaction with its 'greater environment', which will lead to decoherence of the entire state of the composite system U. So we have to admit that system U is essentially open and cannot exhibit unitary evolution.

We can try to improve this model, announcing formally that the environment E is the entire remaining Universe. Then system U becomes closed, because the Universe has no 'greater environment'. This, however, is not possible for the following reason. If we assume that system E is the rest of the Universe, then system U is the entire Universe. It is well known, however, that for the exact quantum state of the Universe the concept of external time does not exist [4], and the evolution of the quantum state of Universe is not a unitary evolution in time. Hence, the unitary description of evolution of system U as time evolution becomes impossible as well.

One can imagine two ways (two programs) for overcoming this difficulty. One way (A) is the construction of a consistently quantum description of the Universe together with the explicit description of generation of internal phenomenological time, indication of the explicit method for describing the subsystems of the Universe, and indication of the method of linkage of these subsystems with the internal time — which amounts to the construction of the complete quantum cosmology. The other option (B) is the phenomenological inclusion of the entire Universe that is external to the composite quantum system U under consideration — using the spontaneous reduction of the wave function, or positive definite operators, or restricted path integral, or some other way. Option (A) seems to be the most consistent; today, however, it is not yet clear whether this program is feasible even in principle. Option (B), as noted by the learned author of Ref. [1], does not lead to logical quandaries or paradoxes. In our opinion, however, it may cause some discontent because, along with the Schrödinger equation, the theory also involves some phenomenology, which is as important as the dynamic laws themselves. This phenomenology is fundamental in the sense that it has to be considered irreducible to any other principle (unlike, for example, thermodynamics, which can be derived from statistical physics). It should have been derivable from quantum cosmology, but option (B) leaves quantum cosmology far beyond the scope of the theory. The problem is further aggravated [and we see this as a logical stumbling block for program (B)] by the fact that such phenomenology can be introduced in different ways, and the equivalence of these ways has not been proved. In our opinion, the problem of quantum measurement essentially consists in the following dilemma: either the quantum theory of measurements is in fact quantum cosmology, or it involves an essential and not quite unambiguous phenomenology.

We have demonstrated that the dynamic description of selection of one alternative by the consciousness is possible within the framework of the unitary model described above. Although this model, as duly noted, is open to criticism, we believe that the feasibility of such a description is an indication that the consciousness of the observer should not be off handedly disregarded in the unitary quantum dynamics, and the principle of psychophysical parallelism on the quantum level cannot be written off.

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Theory of measurements and the collapse of the wave function

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Usp. Fiz. Nauk **170** (6) 631 (2000) [*Phys. Usp.* **43** 585 (2000)] carried an interesting paper by M B Menskiĭ who touches upon some issues related to the theory of measurement in quantum mechanics — in particular, the possible interpretation of the function of consciousness in terms of quantum measurements.

I appreciate the very fact of preparation and publication of this article as a very important and welcome event. As noted in the editor's preface to the paper by M B Menskiĭ (further on referred to as MBM for short), there has been almost no discussion of philosophical issues related to the theory of measurement in the Soviet (as well as in the Russian) scientific literature. This extreme pragmatism of the Soviet (and now Russian) school of theoretical physics, possibly induced by the many decades of ideological pressure, persists unfortunately to this day. Limitations on the freedom of thought always bears negative results. One illustration of this rule is the fact that the Russian theoretical guild (which has produced prominent schools of theoretical physics and mathematics) lags behind in the domain of ideology (algorithms etc.) of quantum computers. One may find some consolation only in the fact that we are somewhat better with applied ideas (for example, with the ideas how to design the 'hardware' for quantum computers).

Going back now to the content of the paper of MBM, I would like to touch upon certain issues on which I do not quite agree with MBM.

Essentially, this letter deals with the following. I present (quite concisely) my view of the theory of measurement (which is a verifiable hypothesis), which holds that quantum theory is a complete theory, and is capable (in principle) of giving a complete description of the interaction of 'quantum' objects with 'classical' ones, the 'reduction (collapse) of the wave packet', etc. The source of 'probability', inherent in quantum mechanics in the standard interpretation, is assumed to be the detector, which may be regarded as a reservoir with special properties (for details see below). In our treatment, it is the degrees of freedom of the reservoir that act as Bohm's hidden variables.

Thus, the selection of an alternative resulting from a quantum measurement is accomplished by the reservoir. As a matter of fact, we hold that the quantum probability is of the same nature as the classical probability associated, for example, with flipping a coin. In the classical case, the measure of the space of initial states leading to the coin landing on its edge is negligibly small; accordingly, in the quantum case this should correspond to the negligibly small

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