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Physical interpretation of quantum mechanics

R S Nakhmanson

The text that follows was written in response to the publication of paper by M B Menskiĭ [1] and the call from the editors of *Uspekhi Fizicheskikh Nauk* [*Physics – Uspekhi*] journal to continue an open discussion of the fundamental physical and philosophical problems of quantum mechanics in the form of "Letters to the Editors". These initial and boundary conditions have predetermined my polemic and summary presentation: in the first part I give critical comments on certain aspects of Menskiĭ's paper, and in the second part I present the fundamentals of the alternative interpretation of quantum mechanics (QM), referring for the details to the original publications.

1. Paper of M B Menskiĭ

In Section 2.1 of his paper Mensky shares the popular opinion that the experiment performed by Aspect's team [2] and concerned with verification of Bell's inequality [3] conclusively blocks the way for the local-realistic models. This, however, is not the case, and Aspect himself knew that. The new thing in Ref. [2] as compared with the experiments carried out in the preceding decade was the fast switching of conditions of registration of photons, which precluded the possibility of a relativistic informational linkage between the particles in the EPR pair. This gave rise to the legend of nonlocality of QM, of the 'instantaneously' correlated behavior of the EPR pair, even though its constituent particles may be hundreds of light-years apart. This, as justly noted in Ref. [1] and elsewhere, is contrary to our 'intuition', to the common sense shaped by our everyday experience — but, as they say, nothing can be done about that.

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Let us see, however, what Aspect writes at the end of his paper [2]: "The switching of the light is effected by acusto-optical interaction of the light with ultrasonic standing wave at 25 MHz, providing a commutation at 50 MHz, i.e. a change of orientation each 10 ns. This time is short compared to L/c (40 ns), but unfortunately it is not possible with these devices to achieve a random switching. In this respect, the experiment is far from the thought experiment".

Another *experimentum crucis* — the so-called 'delayed choice' — was carried out by Alley's team [4]. The special feature was that this team used a random commutation of a Pockels cell in one of the arms of the Mach – Zehnder interferometer.

What is the matter then, and why were Aspect and Alley so keen on randomness? They themselves did not dwell much on that. In 1993 at a conference at Olympia I said to Alley: "In a random sequence each term in the series is unpredictable. Is it that you suspected the ability of particles to predict the situation and wanted to prevent that?" "I guess you're right", — he replied.

To the best of my knowledge, the faculty of prediction was first expressly surmised in 1992 in Ref. [5]. Such a possibility is also assumed in a recent work of Zeilinger's team [6]. This idea leads on to consciousness and its linkage with matter, which is the subject of the latter half of Menskiĭ's paper. There is, however, an important distinction: explicitly in Ref. [5] and tacitly in Refs [2, 4, 6] it is assumed that matter itself is endowed with consciousness, whereas Menskiĭ, in the steps of von Neumann and Wigner, only considers human consciousness.

We shall return to this point later on, meanwhile just noting that if matter has the faculty of prediction, then Bell's theorem does not hold, the local-realistic models of microworld are feasible, and nonlocality is outcast. All this, including the intelligence of matter, can be reconciled with our intuition and common sense. If our ancient nature-worshiping ancestors or the little child of today could use our modern experimental equipment, they would not be surprised by the behavior of elementary particles.

In Section 3 Menskiĭ considers the problem of superposition of wave functions and its transformation upon transition to macroscopic systems ('Schrödinger's cat'). Unfortunately, he falls victim to the common mistake of going too far in identifying the mathematical construct (the wave function) with the material object, whether it is the elementary particle or the cat. Speaking of the space of states, he forgets that it is the space of wave functions rather than a real space, and that the superposition of functions does not imply the superposition of objects. Quoting from the beginning of Section 3:

"As known, the space of states of a quantum mechanical system is linear. This means that, along with any two of its states $|\psi_1\rangle$, $|\psi_2\rangle$, also possible is their linear combination (superposition) $c_1|\psi_1\rangle + c_2|\psi_2\rangle$ with arbitrary (complex) coefficients c_1, c_2. For example, if a point particle may occur at either of two points, it may also occur 'at both points at the same time'. There is nothing like that in classical mechanics. For example, a stone may occur either at one point, or at another, but not at both points at the same time".

This last observation of Menskiĭ is certainly correct, but he is wrong with respect to the elementary particle: no-one has so far observed one and the same particle at two points at the same time, and no-one is likely to do that in the future. Yes, the interference of amplitudes exists in the microworld, and the distribution of probabilities in the registration plane of two-slit experiment is not equal to the sum of one-slit probabilities. Yes, the picture looks as though, from the wave generated by the source of particles the screen cuts out two coherent waves that would interfere with each other to produce the oscillating distribution in the registration plane. All this, however, applies to the wave function rather than to the particle itself, and takes place not in the real space, but in the configuration space that occurs in all likelihood in the mind of the particle and determines the choice of the scattering angle when the particle interacts with the edge of the slit. As far as the particle itself is concerned, it does not 'split in two' according to the two possibilities, but only passes through one of the slits. The same applies to the Schrödinger cat. Irrespective of the numbers and types of waves, including interfering waves, that describe the state of the radioactive atom and the cat, they are only concerned with the probability of decay of the atom and the death of the cat. The atom itself, however, is either decayed or not, and, accordingly, the cat is either dead or alive, and this does not depend on whether we know the state of the atom or not, and whether or not we see the cat. Those who accept the so-called Copenhagen interpretation of QM will argue that the question of which slit was taken by the electron has no meaning as long as this has not been registered, and will not bother about the 'meaningless' questions about the cat.

A special place in Menskiĭ's paper belongs to Section 4 — both in size (almost half of the entire article) and in content. This section deals with the physical interpretation of the very successful mathematical formalism of quantum mechanics — the problem as old as QM itself, and much debated. The solution of this problem Menskiĭ sees in the combination of the many-worlds Everett – Wheeler interpretation and the von Neumann – Wigner idea concerning the role of the observer's consciousness.

Menskiĭ's choice can hardly be regarded as good. According to the many-worlds interpretation, myriads of *real* worlds are born each second, and only a tiny proportion of them have the possibility to recombine with their twin brothers. This interpretation of quantum mechanics is non-constructive, does not render itself to be experimental verification, and does not stand to reason. It is no wonder then that the many-worlds interpretation is now commonly regarded as a pedagogical curiosity, and Wheeler himself has long dropped this idea.

The second component in Menskiĭ's interpretation of QM is human consciousness, which, he believes, performs the selection of alternatives at the quantum level, which eventually leads to macroscopic consequences, and now not only to the deflection of the needle of the instrument: "*The function of consciousness consists in selecting one of the alternative Everett worlds*".

The assumption of the decisive role of human consciousness in the process of measurement (von Neumann, Wigner, London and Bayer) gives rise to a number of questions. For example, whose consciousness is it when we deal not with a planned experiment, but with something that takes place 'by itself', when man is simply an onlooker or even not present? At the end of his paper Menskiĭ writes that consciousness is a fundamental physical property, but "only found in living matter" — that is, not only in humans after all. He does not specify, however, as the reader tends to expect, whether he also implies the selection of alternatives. But is it sufficient to be alive to possess consciousness? And how do we distinguish between what is alive and what is not? What was going on when there was no 'living' matter? Cosmology teaches us that the laws of motion of 'nonliving' matter were practically the same, even though there was no 'living' matter to watch.

There are two possible solutions in this blind alley. One is to assume that the notions of cosmologists are delusory, as illustrated by the dialogue between atheist and priest:

Atheist: "You say that God created the Universe 6 thousand years ago, while science has proved it is at least 10 billion years old!"

Priest: "God created the Universe 6 thousand years ago in such a way that it looks 15 billion years old".

The other way out is to assume that consciousness is inherent in all matter, both 'living' and 'nonliving', and it is the consciousness of the latter that plays the decisive role in physical processes. This assumption (which has a long standing) delivers us from the human solipsism and from the nightmare of many worlds, and provides a natural explanation of the apparent nonlocality and other paradoxes of the quantum world.

2. Informational interpretation of QM

Elementary particles possess a consciousness of their own. There is enough room for that: the typical size of 10^{-18} m will accommodate 10^{50} Planck cells, which is much greater than not only the number of neurons in the human brain, but even than the total number of atoms of all known biological objects. The behavior of particles is purposeful, which is reflected in the teleological nature of physical laws (variation principles). Interacting particles exchange information. They need to have correlated notions about space and time, and in this sense one may speak of the preferred system (like the Greenwich system of time and coordinates). The unity ('holism') of the Universe is informational in its nature. The 'Internet' of matter has probably exist from the time of the Big Bang. A lot of time has passed since, especially in the microworld if one counts events, not hours. One might expect that the civilization of particles has undergone a long evolution. It is possible that this civilization is past its prime already, and is now in the state of stagnation or decline.

The wave function is the strategy of the particle. It is located in the consciousness of the particle and is the result of the work of this consciousness on the known information about the world. The particle is solving a quantum mechanical problem. People have already guessed many rules of this solution and presented them in books and papers on quantum mechanics.

Receiving new information, the particle adjusts its strategy — that is, its wave function. This is the so-called collapse of the wave function. It occurs not in the real space, as is commonly thought, but in the consciousness of the particle — that is, locally and instantaneously on the commonsense scale. Contrary to the views of von Neumann, Wigner and others, in the general case the human consciousness has nothing to do with the collapse.

Two or more particles may have a common strategy. In such a case their common wave function does not decompose into a product of partial wave functions. Being separated, they nevertheless act in a concerted way.

The information available to the particle is the knowledge of the past. For solving the variation problem, the particle must be able to predict what is in store for it. Prediction is a necessary attribute of any consciousness. A consciousness with the faculty of prediction is the nonmechanical hidden parameter that is possessed by the particles and that was overlooked by Bell in the formulation of his theorem. In the experiment by Aspect's team [2] the particles in the EPR pair at the time of separation were able to predict with sufficient accuracy the conditions of registration, since the latter varied in a periodic manner. In the experiment by Zeilinger's team [6] the conditions of registration were governed by a random number generator, based on the 'random' emission of an LED and subsequent 'random' interaction of photons with a semitransparent mirror. In other words, the 'randomness' was borrowed from the object of study itself (the quantum world), which cannot be regarded as reasonable. The authors apparently understand this, because they do not insist on nonlocality, and plan to continue their experiments.

The wave function only sets the priorities. Taking them into account the particle makes a random choice. Such tactics allows for 'impartial' exploration of all alternatives.

What are the experimental possibilities for verifying this hypothesis? Again, we see two possible ways. The first is to prevent the particles from correctly predicting the future, which should lead to nonstandard results. Examples of this approach can be found in Refs [2, 4, 6].

The other possibility is to affect the particles with information . Let us illustrate this with some examples. In Fig. 1 an impulse of polarized light from source S is passed through a 'black box' — meaning that the observer physicist knows what goes in and can measure what goes out, but does not know what is inside the box. In the case shown in Fig. 1a the light that comes out of the box can be either deflected to the right by movable mirror M, or allowed to continue its way forward. Such management of the beam, somewhat like a railway switch, we call 'force management'.

If we place a thick transparent glass plate on the path of the beam inside the box at the Brewster angle to the beam (as seen in Fig. 1a), we do not introduce any absorption or reflection, but the physicist can use his instruments to see that:

(1) (owing to refraction in the plate) the beam going out of the box is displaced to the right by a distance Δz (as shown in Fig. 1a);

(2) (owing to the fact that the speed of light in glass is slower than in air, and the path length is increased) the light will come out of the box with some delay Δt.

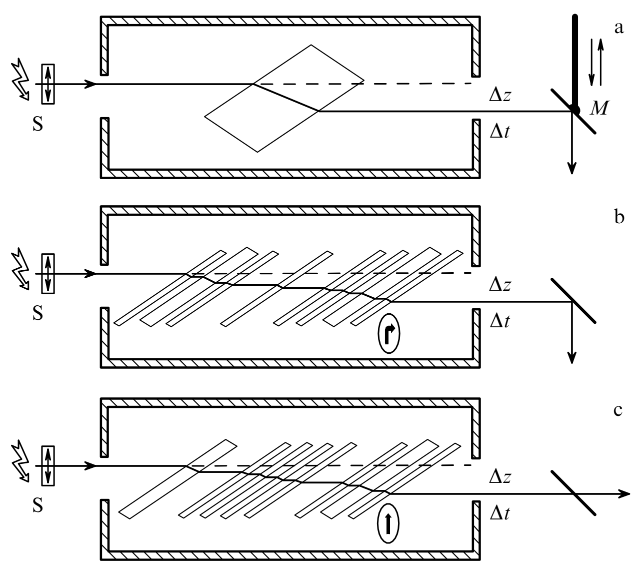

Figure 1. Force (a) and information (b, c) management.

And this is all that the physicist can find out without looking into the box.

In Figs 1b and 1c in place of 100% mirror M we have fixed semitransparent mirrors, and the thick plate is split into 8 thin plates of which two are thicker than the rest. Our physicist will not notice any of the changes made inside the box, because he will measure the same Δz and Δt. The photons, however, if they are intelligent and know English language and the Morse code, will read the following instructions:

• – •   •   • • – • = REF (reflect) in Fig 1b, or

–   • • • •   • – • = THR (through) in Fig. 1c,

and carry them out by reflecting in Fig. 1b or passing through the semitransparent mirror in Fig. 1c. Such management of the beam, like the traffic lights at a crossroads, may be referred to as 'informational management'.

Note that carrying out of such 'informational' experiments with elementary particles differs from anything that has been done in physics so far.

It is possible that the particles actually know all human languages and codes. But it would be safer to assume that we are dealing with a totally different civilization that knows nothing about us, so that our first contacts will run into difficulties. This problem is not new, and has been seriously considered in the framework of the Search for Extraterrestrial Intelligence project SETI. Its experts are inventing 'cosmic' languages capable of developing communication from zero to a high semantic level. At the initial stage one could recommend trying such universal languages as mathematics and music. The starting point for identifying intelligence that may be much unlike ours, and for trying to establish contact with it, should be some very general property presumably inherent in any kind of intelligence. A good candidate for such a role is curiosity.

Figure 2 shows the scheme of a 'binary tree' experiment that does not presume that the particles are aware of our culture in any way. The initial beam of photons enters the tree trunk (from below in Fig. 2), and then branches out with the help of 50%-transparency mirrors, shown in the diagram by circles. Our scheme in Fig. 2 only has five rows of mirrors, but in principle the more the better.

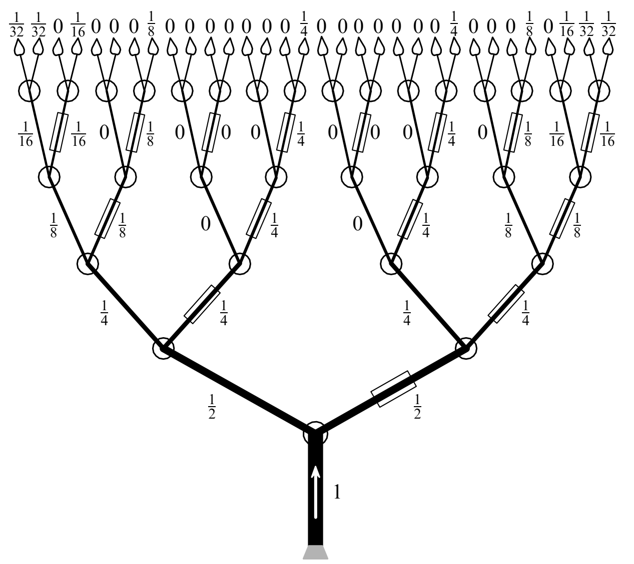

Figure 2. Binary tree. Numbers indicate the probability of the particle occurring in different branches of the tree in the case of momentary formation of a conservative conditioned (conditional) reflex.

According to current views and experimental practice, all outgoing beams (Fig. 2 top) have the same intensity, which is 1/32 of that of the initial beam (of course, real mirrors will not have exactly 50% transparency, and there will be some absorption, but this is not important).

Now we introduce into all the right-hand branches (corresponding, for example, to reflection by the mirrors) the 'informational cells' (shown by rectangles), which convey some information to the particles. These cells may be represented by the sets of glass plates in which the information is encoded in the thickness of the plates and the distance between them. The information conveyed by each subsequent row of cells is a continuation of the information conveyed by the previous row.

Real cells introduce some absorption, which can be taken into account in processing of the experimental data, or compensated by installing similar cells in the left-hand branches, which carry 'less interesting' information. For example, if each letter of our alphabet corresponds to a plate of certain thickness, then the left-hand cells may have the same plates arranged in alphabetical order.

According to the current views and practices, the introduction of informational and compensating cells will not affect the equal distribution of the intensity in the exit branches. If the particles have intelligence, however, they may take interest in the information presented to them. Trying out different paths, they will discover that the right-hand branches carry more information, and will prefer them to the left-hand branches. In other words, the particles will develop a conditioned reflex. This will alter the distribution of particles in the exit branches. Figure 2 shows an example of the probability of the particle occurring in different branches of the tree in the case of momentary formation of a conservative conditioned reflex — that is, when the particle after the first comparison of the right-hand and the left-hand branches immediately begins to give total preference to the right-hand ones.

The unequal distribution of particles in the exit branches may be detected by the experimenter, and can be rightly interpreted as an interest of the particles towards the information, and a manifestation of their intelligence. This important result does not even depend on the ability of particles to decipher information — it is sufficient that they are curious. It is like archaeologists traveling to remote places because of their curiosity for ancient hieroglyphs, long before they learned to read them.

The sum of information distributed in the cells may be a kind of a course teaching the particles a language for further dialogue. To measure the progress of learning, the experimenter from time to time may present the particles with the instruction "Please turn left". Since the particles, eager not to shirk the lessons, will tend to select the right-hand branches, the execution of this instruction will mean that the text was decoded, and we have moved to a higher level of information contact.

The scheme in Fig. 2 can do even more. By selecting a unique path, the particle may use the 'right – left' code ('0' – '1') to transmit a message. Since the detection of the particle in the exit branch corresponds to the unique path in the tree, we shall be able to read this message. For example, the leftmost branch in Fig. 2 corresponds to the message '00000', and the rightmost to '11111'.

This interpretation of QM is also developed in Refs [7 – 9].

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Reality and the main question of quantum information

A M Pilan

As a matter of fact, the main issue in M B Menskiĭ's "Quantum mechanics: new experiments, new applications and new formulations of old problems" is concerned with the information that is available in Nature for the (pre)determination of quantum histories.

After 75 years of debate many practical scientists do not believe in the expedience of discussing either the quantum paradoxes or the concept of information for physics. On pages 13 and 15 of *Physics Today* (February 1999) Anton Zeilinger cautiously observes that "after the success in demonstrating the entanglement, it will not be a big paradox if it turns out that quantum mechanics is about information", but is cut short by Goldstein: "does Zeilinger truly believe that information can simply and generally exist just by itself? — it always is about concrete things and events... — this is why it is interesting at all". So what is the quality and quantity of the determining information available in Nature?

The appeal to the multiplicity of parallel worlds constructed by the consciousness — which essentially is a turn to the philosophy of solipsism, presented in the review of M B Menskiĭ [1], might well be regarded as an indication that the situation is desperate. If we look at the role of 'God' from the cybernetical standpoint, however, we must admit that God will hardly take care of each of the alternative fates of all microsystems. As my contribution to the 'brainstorming' started by *Uspekhi Fizicheskikh Nauk* [*Physics – Uspekhi*] journal, allow me to share my conjectures about the form of presentation of quantum information.

We are living through the crisis of revision of QM from a mechanical machine to an information-cybernetic machine. If there is enough determinism in quantum mechanics to make

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