Subquantum leapfrog

Lev I. Verkhovsky (Moscow)

An independent researcher and scientific journalist (http://lev-verkhovsky.ru/)

Abstract

A new interpretation of one of the central concepts of quantum mechanics -- the reduction of the wave function in the measurement -- is proposed. The applications of this approach to various phenomena of the micro world are discussed. The main provisions of this article were previously described in the article "Субквантовая чехарда», published (in Russian) in the Russian popular science journal «Chemistry and Life» (Химия и жизнь, 2005, No. 9).

...I feel that after seventy-five years –

and innumerable successful applications –

we are still two big steps away from understanding

quantum theory properly.

Frank Wilczek (2000)

In the twenties of the XX century, there was a scientific revolution — originated quantum mechanics. Its main feature — the wave-particle duality and associated principles of uncertainty and complementarity. Noting the duality and mystery of this theory, the German physicist Theodor Kaluza called it "the Sphinx of modern physics".

Some founders of a new mechanics believed that it had already acquired its final form, others that it's just a preliminary theory. The debates began at the Fifth Solvay Congress in Brussels (October 1927), where Niels Bohr outlined the main provisions of the so-called "Copenhagen" interpretation and Albert Einstein expressed his objections.

Since then the discussion does not cease, moreover now after eighty years it perked up. In our days quantum mechanics continues to be a Sphinx. However, most experts believe that there is no reason to worry — the theory does work well, allows the calculation of different effects. But man is not a calculator, he wants to have a complete and consistent picture of the phenomena.

What is the meaning of reduction?

The logically quantum theory consists of two quite dissimilar parts.

The behavior of a micro-object is described by the wave function, which is obtained as the solution of the Schrödinger equation and which varies strictly deterministically. In the general case, it represents a linear combination, that is the sum of many other functions (multiplied by certain coefficients), each of which corresponds to one possible state of the object (so-called a superposition of states). This is the first part where we have no randomness.

During the measurement procedure, and this is the second part, a jump happens — the reduction of the sum to one of the components (or some subset of them). This process is called reduction, or collapse of the wave function. And just here chance manifests itself: it is impossible to predict in advance to which member (or group members) of a set it will be reduced -- are known only probabilities of each option.

How to interpret superposition of states and probabilities of the jumps during the measurement? This is one of the key problems. It was proposed a lot of different answers, but they can be divided into two main groups.

One widespread opinion: it is necessary to consider a large collective, or ensemble of particles in the same conditions, which are the subjects of measurements. Each particle is in one of the possible states. As a result of many measurements, the statistic will give a certain frequency of appearance of each of them in accordance with their probability.

According to the other (Copenhagen version), any micro-object exists simultaneously in all possible states, and probabilities describe the potential of each of them to be registered in an experiment. In other words, there coexist many alternatives, and a particular state of a physical system arises only at the time of measurement.

Not all scientists were satisfied with this not too clear phenomenological scheme and they asked the question: what physical reality lies behind it, where probabilities do come from? Recognizing the efficiency of quantum mechanics, Einstein was convinced that it incompletely covers the phenomena and we need to improve our understanding.

Following the model of thermodynamics

In fact, this is not the first theory, where the randomness manifests itself. There is a good example -- statistical physics, which starting from the processes at the level of atoms and molecules (micro-level) explained the laws of thermodynamics (in macro-level). Studying, say, the behavior of the gas, we can`t measure the values of all parameters of each atom or molecule and therefore appears a probability. But if we knew these parameters, the description would be totally deterministic.

The intuition of Einstein and his followers suggested to them that in the quantum world must be something like that. So, we need to enter into consideration a lower – subquantum -- level. Perhaps in it, there are parameters whose values affect the outcome of an experiment; we don`t know these values, therefore events going on the quantum level we perceive as random. But then immediately the question arises: if the subquantum level is essentially unavailable, inaccessible, then maybe talks about it are just fruitless speculations? Such, in particular, was the opinion of Werner Heisenberg.

Remember, however, that Ernst Mach and Wilhelm Ostwald rejected the hypothesis of Ludwig Boltzmann about atoms, considering his treatment of thermodynamics as speculative. But in the end, Boltzmann won, as he was able with a single point of view to explain a wide range of phenomena. The same can be expected for the microcosm from theory based on the idea of hidden (from us) parameters.

David Bohm, Louis de Broglie, and other physicists tried to implement this approach. Their opponents (from Copenhagen) said: every object is a black box, so to discuss its internal structure is useless. Mathematician Janos von Neumann even proved in the 30-es a theorem: quantum mechanics with hidden parameters will have contradictions. But enthusiasts of hidden parameters put forward a counter-argument: every proof is based on accepted postulates and can lose their value when they change.

What are the properties of the hypothetical subquantum level? Let's try to approach this mystery from the... chemistry. Usually, in order to understand some phenomenon, researchers seek its simplified model, but sometimes the desired pattern more clearly manifests itself in a more complex system. And such a system will be for us a molecule.

How to take a picture of a molecule?

How do we imagine the spatial structure of the molecule? Clear that it is not a static but very dynamic essence. It has the set of admissible states separated by potential barriers of different heights (electronic isomers). Molecule tunnels from one state to another and each of the possible leaps occur with a certain probability.

Our conception of the molecule depends on the time resolution with which we observe it. Each experimental method has its characteristic time of interaction with the molecule. For example, in electron diffraction (in sec.) -- 10 in the minus 20th-degree; for the x-ray -- 10 in the minus 18th-degree; UV spectroscopy -- several orders more; NMR -- many orders of magnitude greater. Different methods yield very different "portraits" of the same molecule (as if we change the camera shutter speed at which make the photo). A classic example – a molecule of ammonia. Three hydrogen atoms in the NH3 form an equilateral triangle and this trio performs synchronous oscillations with respect to the nitrogen atom, jumping from one extreme position to another.

If we apply the fast method, such as electron diffraction, we will detect three protons on one side of the atom N and see a triangular pyramid. If a method is slower, say NMR, will see a triangular prism (with the nitrogen atom in the centre) -- averaging structures corresponding to both possible extreme configurations of hydrogen atoms. Importantly, many observable physical properties of a molecule also depend on the used method (in the pyramid there is a dipole moment, whereas in the prism it absent).

With similar things, we encounter in everyday life. So if we look at the vibrating string, the period of oscillation is significantly less than the time interval of visual perception, we see it spread over the entire space between the two extreme positions. We do not know where that vibrating string is localized at this moment, but able to calculate the probability of its various locations. By the way, on the same principle of averaging consecutive frames bases cinema.

Pay attention, that when different states are waves then as a result of their overlapping each other an interference pattern will come into being. The same is true in the case when all the waves do not exist simultaneously, but follow each other successively -- fast enough relative to the method of their surveillance. And here lies the key to explaining the "archetypal" (Roger Penrose) experiment on passing single particles through a screen with two slits.

Quantum cinema

And now -- our main idea. Let's assume that (similar to molecules) any isolated quantum system does not stay in one particular state (as advocates of ensemble approach think), but make frequent spontaneous jumps from one to another. The behavior of such a system is determined by probabilities of various transitions and the mean residence times at each of the stops.

The various alternatives do not exist (as believe supporters of Copenhagen version) in every moment all at once. Instead, they alternate in time (psychologists would say that the process is not simultaneous but successive). This random alternation of states -- "leapfrog", in our opinion, is the physical meaning of their superposition.

And what will a measurement mean in this case? We fix the micro-system in the concrete state in which it exists in this moment, so to speak, we see a separate frame of film (or -- when the interval of interaction is more -- we only narrow the spectrum of alternatives). This is the essence of the reduction of the wave function.

Probably spontaneous jumps have their root causes, which are still not known. But even if we can never penetrate in this subquantum world and learn the details of what is happening there (although Boltzmann atoms became a common object of study), this idea is able to make the quantum theory more understandable and coherent.

(It can be assumed that all ultrafast transitions at the subquantum level are strictly deterministic, and the micro-system behaves like a finite state machine. Randomness arises from the fact that when we measure, we invade the process at random instants of time.)

The principle of leapfrog gives a fresh look at the different quantum phenomena. I the past a lot of noise was raised in our country (USSR) around the Linus Pauling`s concept of "chemical resonance": in it, any molecule is thought as a superposition or a hybrid of several so-called resonance structures that coincide on the location of atomic nuclei, but with different electronic configurations.

Hybridization can probably be interpreted as a result of superfast -- on all available methods of observation -- transitions from one electronic configuration to another (electronic isomers). The nucleus of atoms are massive, they have not kept up with electrons and therefore remain stationary. As a result, all the alternatives are averaged taking into account the weight (probability) of each of them.

Another field of science is quantum field theory. It describes the interaction between particles as the sum of infinite series, whose members correspond to all possible exchanges of virtual particles. Each option is represented by its Feynman diagram and has its own probability. Here, I guess, we see again the same leapfrog of states.

Rest -- only in our dreams

Natura non facit saltus... Perhaps philosophers were wrong and nature does make leaps on the fundamental Subquantum level; the matter is initially active and changeable, particles are labile — they adjust their behavior to the milieu. Then the gap between the living and the inanimate, the spiritual and the material becomes a little less deep.

Quantum mechanics itself, too, looks like a superposition of many interpretations — we have already more than a dozen and it is not the end. Physicist John Trefil has even formulated a set of laws that govern the discussion on this topic: 1) any physicist has the right to offer their own interpretation; 2) there are no two identical approaches; 3) every author believes that only he is right (it is possible that it was an April joke — see the "Science" of April 9, 2004, p. 212.)

Speaking seriously it can be argued that the lack of understanding of the micro-world is increasing, and this fact gives hope for a breakthrough to the new knowledge. I hope that some role will play my hypothesis of subquantum leapfrog. Maybe now it looks a little vague, but I was just following the advice of Niels Bohr: "Never speak more clearly than you think."

===