

One of the questions in quantum physics that has no clear answer is what is the nature of wave-particle duality. The journal Nature conducted a poll ("Physicists disagree sharply about what quantum mechanics tells us about reality, Nature poll" July 30, 2025), the results of which showed that not only is there no consensus on the issue, but most authors are unsure of their views on the nature of this phenomenon. This work is based on the opinion that a person perceives the surrounding world as a set of mental representations, the source of which is the material world. The key thing is that the world has a dual nature. At the same time, there is a real material world and a real mental world, like two sides of the same coin. It is necessary to distinguish between the mental and material manifestations of the world and not to take one for the other, but also not to ignore one of them. This text offers the new explanation of how an elementary particle (photon) can exhibit the property of a corpuscle and a wave and what conditions are needed for this or that manifestation. As an instrument for understanding this, the retina of the eye, consisting of specialized photoreceptors, is proposed. The explanation is preceded by a large introductory part, which contains arguments for the proposed opinion.

A bit of history There is an opinion, existing since the emergence of empirical science, that the entire surrounding world, including living beings, belongs to the material world, and can be considered due to their physical properties. A special problem is posed by the quantum world phenomena, the parameters of which go beyond the capabilities of ordinary human perception. As writes Van Fraassen (1980), they are unobservable objects (we consider them non-anthropomorphic), in contrast to observable (anthropomorphic) objects, the parameters of which are perceived by human sensory systems. Elementary particles are non-anthropomorphic objects. The impossibility of direct observation of their behavior was the cause of the famous dispute about their nature between A. Einstein and N. Bohr, in which Einstein considered particles to be material, and Bohr - ideal. The problem of wave-corpuscle duality is how a quantum "knows" where it should manifest itself as a particle and where as a wave. Of course, "knows" is a metaphor, but the reason why this quantum can be registered in an experiment in one form or another remains a matter of debate. The first explanation of this phenomenon, called the complementarity principle, was given in 1927 (the "Copenhagen interpretation"). Bohr and Heisenberg proposed the uncertainty principle, which they understood literally and interpreted from the standpoint of subjective idealism. The idea was that matter has no properties until it is endowed with these properties by the experimenter conducting the experiment. They believed that outside of measurement, a particle is simultaneously in many places, and the process of measurement, interaction with the experimenter allows matter to take on a certain state as a result of exposure. Later, the Heisenberg-Fock interpretation was proposed, according to which this or that manifestation of a quantum was associated with the effect of the device on the object under study (the observer effect), as if the device endowed it with the expected property. How can a device or an experimenter operating the device influence an object during the study so that it manifests this or that property? An anthropologist would call this a manifestation of everyday magic. The very setting of the experiment, the setting of the problem allows one to see in the object only the manifestation that the study is aimed at. Here it is appropriate to recall the phrase: "If your only tool is a hammer, then all problems seem like nails."

It is easy to see that in these formulations the methodological and philosophical position of the authors plays a significant and even decisive role. As mentioned, Einstein in his dispute with Bohr did not agree with such an explanation, which, in his opinion, meant "the disappearance of matter". Not all physicists accepted this theory; there are other types of interpretation of dualism in quantum mechanics.

Methodology used Protagoras is the author of the famous thesis: "Man is the measure of all things." Since antiquity times, man has been considered a microcosm corresponding to the external macrocosm. It was believed that even the laws of human life are similar to the laws of the macrocosm. This is true, but not the whole truth. As is known from cybernetics, the smaller cannot judge the greater or more complex, but only the smaller or less complex than itself. The problem of the possibility of knowing the world was solved by Descartes, postulating that it is possible to judge the surrounding world only with the help of models. Models are mental constructions (if necessary, embodied in material), which in a simplified, reduced form represent their prototype. The attractiveness of ancient statements is not only that they show the possibilities of judgments about the surrounding world, but also show the limitations of these possibilities, it is enough to apply to them not only cataphatic, but also apophatic analysis. The emergence of man occurred

in a state of co-evolution with the surrounding nature. The developed world, likened to man, corresponding to his needs and capabilities, is only a part of the universe, the anthropomorphic part. Moreover, as Jacob von Uexkull wrote about this material part of the environment (1940 and elsewhere), man knows about it only “as if”, since he judges not the immediate environment, but through those signs, the source of which is the mastered reality. These signs, according to Uexkull, form the Umwelt - a mental representation of the world, which for man largely plays the role of the macrocosm. The anthropomorphic world as applied to physics is the subject of interest of classical physics. But quantum physics studies the world that is incomparable, not proportionate to man and inaccessible to direct perception - a non-anthropomorphic world, which explains many methodological difficulties and problems. To understand what determines the position of a researcher, one must turn not only to philosophy (more precisely, to that part of it that serves as the basis for the methodology of science), but also to his biology, which determines the possibilities of perception and interpretation of the surrounding world.

A bit of biology, psychology and semiotics A person is a likeness of the surrounding world, but more precisely, one can say that the surrounding world is likened to a person in his perception. To explain this, we must turn to the Umwelt theory of the above-mentioned Jacob von Uexkull. This theory is the basis of biosemiotics, which unites biology, semiotics, cognitive science and is also largely useful for philosophy. The meaning of this theory is that living beings know about the surrounding world only what they can perceive, using their sensory and motor systems for research. Perceived signals are interpreted as signs, the totality of which constitutes the Umwelt as a representation of the world assimilated by the organism. In addition to the Umwelt, there is the Innenwelt - this is the internal part of the organism, limited by the integuments of the body. It is this that determines the direction of exploration of the surrounding world, solving the problem of ensuring the vital functions of the organism and, thus, determines the limits of interest in the surrounding world. In different organisms. The sign acquires meaning as a result of the interaction of the external and internal. Umwelts differ in accordance with their capabilities and needs, Umwelts are individual. All these conditions limit the parameters of human Umwelts, they are built in accordance with the limited possibilities of perceiving the parameters of the external world, which are the sources of signs, and, accordingly, the set of these signs is limited. The peculiarities of Umwelt structuring are associated with two phenomena. Firstly, it is a consequence of the processes of individuation and separation (Mahler, Pine, Bergman, 1975) in the development of the child’s psyche, when he learns to distinguish himself from the surrounding world and recognize his individuality. Secondly, it is the individuation of objects and phenomena of the surrounding world, the ability of a person to separate them and endow them with meaning. This is facilitated by the fact that a person lives in a world of things created by him, each of which is the embodiment of a mental idea that has an original meaning. These processes are important for the formation of the psyche, the formation of human-type consciousness, for the development of verbal language that describes not only situations as a whole, but also its individual elements. Human language is represented mainly by words - complex signs, “signs of signs” (according to I. P. Pavlov, this is the second signal system). The question of the individuation of things is related to the global problem of the relationship between the general and the particular. The ideas about particular, concrete, individual things have their source in the general ideas about how universal forms become particular things. The origins of this problem are found in antiquity, it was actively developed by the scholastics and now this topic has turned out to be in demand for the development of artificial intelligence. In another interpretation, this topic can be presented as the relationship between the discrete and the continuous.

Discrete and continuous These two phenomena are two sides of the same coin in the relationship between a person and the outside world. The initial environment and the processes occurring in it are continuous. The world is constantly changing, developing, but it is possible to formalize this only with the help of “instant snapshots”, the allocation of discrete states. There are differences in the perception and interpretation of the discrete and the continuous. Animals, unlike humans, perceive the world continuously; for them, a sign simultaneously denotes both a situation and an action associated with it, united by a common meaning. They do not separate the designated object from the circumstances, but place it in the semantic center of the situation. This is well illustrated by the description of the setting of experiments on the development of conditioned reflexes in the laboratory of I. P. Pavlov (1951). People, due to their original animal nature, are also capable of perceiving the world continuously. But, firstly, this is interpreted not by verbal language, but by simpler signs inherited from animals. These signs constitute the paralinguistic part of language, this

is a demonstration of movements and emotions. Secondly, specific human properties cover, disguise more ancient properties.

A rational description of continuous phenomena requires that they be represented as a set of separate fragments. For processes, this is similar to how in a movie the illusion of movement is created by alternating frames. In scientific research, formalized numerical data about an object is used. In anthropomorphic research, two main digitalization methods are used for digital processing of a continuous variable signal: pulse (measuring “peak to peak” at a given height of the signal amplitude) and analog (measuring the signal amplitude with a given frequency), which allows us to interpret the results with acceptable accuracy as a continuous envelope of fixed amplitude points. Such fragmentation allows us to make measurements and create a mathematical model of the signal. But we must remember that a model always contains less information than its prototype. As we know, “the map is not the territory.” This problem of explaining the coexistence of the continuous and the discrete became obvious after it was discovered that elementary particles under various experimental conditions exhibit either discrete, corpuscular, or wave, continuous properties. This manifestation of corpuscular-wave dualism has no analogues in the anthropomorphic world and, therefore, does not lend itself to the interpretation existing in classical (anthropomorphic) physics, which is oriented toward discrete objects. It became necessary to propose a new interpretation.

Photons and Living Beings The very fact of interaction of living beings with light (electromagnetic radiation of the visible range) has long been well known. Here are the most famous examples, which are far from exhausting the whole picture: - processes where photons are perceived by photosynthesis in plants, perception of light by the retina of the eye in the process of receiving visual information; - processes of photon emission: biophotoluminescence, accessible to direct observation from the outside, participation of photons in signal transmission in the brain through synapses. Synaptic transmission of this kind can be observed on the open brain, but the method has significant limitations due to the weakness of the signal - it is necessary to have special image amplifiers, and the observation zone must be close to the surface. The listed phenomena bypass the problem of dualism, since practical interests do not require taking it into account.

The phenomenon of dualism is known not only for elementary particles. It has also been shown for complex molecules. In 2019, diffraction of molecules with a mass of more than 25,000 amu, each of which consists of almost 2000 atoms, was proven (Fein, et al, 2019). The presence of a de Broglie wavelength in objects heavier than the Planck mass (approximately the mass of a large bacterium) has not been confirmed theoretically or experimentally (Arndt, Hornberger, 2014). It has been shown that the larger the particle, the more difficult it is for its wave properties to manifest themselves. Proof of the manifestation of dualism in larger molecules requires a revision of modern physical theories (Bergmann, 1992). Photoreceptors have already attracted attention as a prototype for ultrasensitive research tools, namely, they were used as a neuromorphic vision sensor for wide-field quantum scanning of diamond (Z Du, 2023).

Object vs. object The word “object” has many meanings. We understand an object as something that the subject’s activity is directed at. This something is a mental representation of a thing, a fragment of material reality, observed directly or assumed on the basis of indirect manifestations. The term “object” in classical and quantum physics has different meanings. In classical physics, a thing and phenomenon are an element of the material world, it is concrete, and an object is a generalized mental representation of an object, a thing and an object are closely related, they are often not distinguished. A thing is the source of the entire set of properties and manifestations, both known and unknown, and an object contains only those properties that the experimenter studies. The task of science is to clarify the properties of a thing, therefore the results obtained on objects are interpreted as the properties of their sources. In quantum physics, little is known about the material nature of the particles being studied, some authors believe that they do not exist, but study objects by indirect manifestations. What is an object in this case, what properties do it represent? It must be acknowledged that the material basis of what serves as the basis of an object in quantum physics has, from the point of view of the usual description, fundamentally different qualities than the material world of classical physics. Some properties seem so unusual that this world is interpreted as ideal. One can object to this, referring to the results of the experiments mentioned above, that the phenomena of dualism are also inherent in large molecules, which can be studied directly.

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Beyond anthropomorphism Quantum particles are not particles or waves, but something third, they manifest themselves as a particle or wave only depending on the observation conditions aimed at registering the properties of a wave or particle. It is difficult to say what other properties they have, if any. We cannot even estimate the scale of our limitations and how great our capabilities are for understanding their nature. That is, we judge particles indirectly, using the ideas we ourselves create about them. It is difficult to get an answer to a question that is not asked.

In classical physics, it is considered that the experimenter knows about reality what he judges by means of direct observation, in contrast to quantum objects, which are judged by indirect manifestations. As has already been said, the non-anthropomorphic world differs from the anthropomorphic world not so much in the size of its objects, but in that the existing methods of understanding and interpreting objects were created for a limited circle of objects, and the boundary was determined by the connection with human capabilities, anthropomorphism. It is necessary to understand how one can imagine the world if one abandons one's anthropomorphism as much as possible. To go beyond the anthropomorphism of perception and interpretation, one must abandon the perception of objects as particles or as waves, that is, the object must be perceived as a unity of the discrete and continuous. At the same time, there is no guarantee that the objects do not have other manifestations about which questions have not been asked.

To do this, it is necessary to imagine what the perception of the surrounding world would be like if we reject the results of human processes of separation-individuation and individuation of objects of the surrounding world. We can recall that animals perceive the world continuously, without singling out the object of their interest from the surrounding background, but only attributing central significance to it. Literally, this means that light can be perceived as a stream of photons not due to the instruments used for observation, but due to the conditions created for observation, due to the characteristics of the background against which the photons exist. The same can be said about the possibility of observing light as electromagnetic waves. The question is, what are these conditions?

Light and the eye We propose to consider the human retina as an instrument, where the processes of light perception occur at the quantum level. Using the human eye gives a unique opportunity to look at the result of the impact not from the outside, not from the position of the subject and object, but with the help of the self-report of the owner of the eye.

We base our argument on the fact that quantum objects exhibit particle or wave properties depending on the experimental conditions, not the expectations of the experimenter. The first question that a physiologist studying the visual sensory system asks himself is how a quantum of light acts on the retina of the eye, causing a visual sensation. This process is studied, is given in all textbooks and is considered known as the action of light on the layers of the retina, where a nerve impulse arises, transmitted further to the brain. In this case, whether light exhibits the properties of a photon or an electromagnetic wave is important only in that the wavelength determines the color, if the study of color effects is part of the experimenter's task. We believe that the retina reacts differently to corpuscular or wave manifestations of a photon. We proceeded from the fact that since a particle acts, then in theory the other hypostasis of the photon should also act. The basic idea is simple: a beam of light as a set of directed photon flux acts on the retina as corpuscles, and deflected photons, those that have left the beam or that were not originally in the beam,

exhibit wave properties. The structure of the eye is such that the light entering the eye passes through the lens as if through a lens and enters the central part of the retina, consisting of cone photoreceptors that perceive a color image in a situation of good illumination. The peripheral part of the retina is covered with photoreceptors of another type - rods, which are responsible for dark vision, vision in the twilight, when the clarity of objects disappears and gray-black figures are visible. Obviously, significantly fewer photons fall on the rods due to their peripheral position than on the central cones (a kind of diffraction) and, in addition, in the twilight the density of the light flux drops sharply, down to single photons in complete darkness. This eye structure allows us to think that light corpuscles need to be close to each other, have a flow density, and a high concentration per unit volume to manifest themselves as particles. Photons, which exhibit wave properties, on the contrary, need to be quite far from each other.

This view provides a simple explanation for why the largest of the mentioned objects - large molecules - exhibit more particle properties than wave properties. Apparently, the larger the object, the more difficult it is to create wave-like conditions for it in an experiment. It is difficult not only in an organizational sense, but in understanding the need to maintain sufficiently large distances between particles. We believe that black is a color, not the absence of color. The brightest black is seen in a special room where there is no influx of light and bright black without admixture of another color is provided by a small number of photons not absorbed by surfaces. It can also be in daylight, as an important component of the resulting image, in particular in graphic images, drawings and, especially, in font, without which there would be no written language. Like other sensory systems, the visual system has the property of adapting to changes in the level of illumination in a limited range, increasing the level of sensitivity to a weakened signal. Increased sensitivity to low illumination plays a role in protecting against sensory deprivation, when the illumination is so low that mainly a black background is visible and objects are almost indistinguishable. With closed eyes we see spots of indefinite shape, the color of which is determined mainly by a small number of photons penetrating through the eyelids. A complete lack of influence on the retina occurs when a person falls asleep. In this case, he either sees and remembers nothing, or sees dreams as a projection of images from memory.

There is an inspiring idea that the world is structured as a large fractal. It is a pity that the identity of areas of different scales exists only in a mathematical model; in reality, only some similarity is possible. If we use the idea of this similarity, we can recall the properties of some substances familiar to us. Take water, for example. It has three main aggregate states: solid, liquid, and gaseous. A piece of ice can be likened to discrete, liquid water to continuous with a limited volume, and gaseous water to continuous with an unlimited volume. The state can be changed by heating or cooling, as a result of which the relationships between molecules change, determining the distances between molecules. Could this be an analogue of discrete and continuous for the manifestation of quantum dualism?