Quantum-mechanical analysis of the wave–particle duality from the position of PQS.

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Abstract: The wave-particle duality of elementary particles is analyzed using the principle of quantum superposition (PQS). It is shown that the elementary particle can no longer be regarded as a corpuscle (or as a material point), but also it cannot be regarded as a wave. A real elementary particle, for example, an electron, is a phenomenon of a higher level in which both the corpuscle and the wave are only particular manifestations of the complex internal structure of the particle. Using the oscillation hypothesis of Louis de Broglie (together with the principle of PQS), an elementary particle can be represented as an oscillator, in which the kinetic and potential energy completely transform into each other with a certain frequency.

Keywords: principle of quantum superposition, wave-particle duality, Louis de Broglie oscillatory hypothesis, elementary particle, "particle-oscillator" model, "time quantum of the electron".

INTRODUCTION.

At the moment we do not have a complete understanding of what an elementary particle is (for example, an electron or a photon). And it is precisely this ignorance that multiplies the various interpretations of quantum mechanics that have nothing in common with objective reality, and which "connect" the observer and our reality and their "interaction" among themselves (the "influence" of the observer on reality is very much like a "perpetuum mobile"). Here it is necessary to add that with the various interpretations of quantum mechanics as an axiom, it is assumed that an elementary particle must be a particle (a corpuscle, a small ball), but this assumption, as will be shown below, does not correspond to reality (this is also confirmed by the classical radius of an electron).

From the experiment with double slits it follows unequivocally that an electron (or a photon, or any other elementary particle) can manifest itself both as a particle and as a wave, and this is an experimental fact. But it should be understood that the same electron (or photon) can not simultaneously be a particle and a wave, it follows logically from the principle of quantum superposition and the very essence of quantum mechanics [1, 2]. A comparison of the principle of superposition in the classical and quantum sense will be very clear [2]:

"The superposition of the states of quantum theory differs significantly from the superposition of oscillations in classical physics, in which the superposition of oscillation with itself leads to a new oscillation with a greater or lesser amplitude. Further, in the classical theory of oscillations, there is a state of rest, in which the amplitude everywhere is zero. In quantum theory, however, the equality to zero of the wave function at all points in space corresponds to the absence of a state".

This quotation actually directly indicates why quantum mechanics is a set of discrete values of certain physical quantities, and classical mechanics is a continuous spectrum of values of the same quantities. The explanation is simple: in the classical theory of oscillations there is a state of rest in which the amplitude of oscillations is zero, and which is a superposition of other oscillations. In quantum mechanics, with the superposition of states ("quantum oscillations") it is already impossible in principle to obtain a state of rest in which the amplitude will be zero: we will always get a new quantum state, which will have a discrete spectrum of initial values of physical quantities. But, since any existing quantum state has a "vibration amplitude" other than zero, in fact, the principle of quantum superposition "cancels" quantum states in which the "vibration amplitude" will be zero (or the values of real physical quantities). As a consequence, we obtain that the lower energy level of any quantum system will always have a nonzero value: for example, the "zero oscillations" of a harmonic oscillator, an atom, a vacuum, etc.

"Zero oscillations" are inherently quantum fluctuations of the system in the ground state (this is the state with the lowest energy) and owe their existence to the Heisenberg uncertainty principle.

The energy of the "zero oscillation" of the harmonic oscillator is

$$E_0 = (h*\gamma_0)/2$$

where h — Planck's constant, and γ_0 — frequency of zero oscillation. The same formula determines the energy of zero oscillations of the physical vacuum.

Naturally, any other real physical quantity in quantum mechanics at the lowest quantum level ("zero quantum state") will always have a nonzero value. This is fundamental and undeniable, and it is this that is the very essence of quantum-mechanical phenomena.

From the foregoing it follows logically that an elementary particle is not a particle, and is not a wave: a particle and a wave are just different facets of what an elementary particle actually is. For comparison, we can give an analogy with the cube: let the cube represent an elementary particle, then when we see (register) the edge of the cube, we fix the particle, when we see (register) the face of the cube, we fix the wave. From this analogy it is easy to understand why an elementary particle is not a particle (a corpuscle, a small ball) and is also not a wave, a corpuscle and a wave are its "visible" facets (characteristics), an elementary particle is something of a higher order (and more complex). In principle, this follows strictly from the principle of quantum superposition. Let's go to rigorous proof.

RESULTS AND DISCUSSION.

Consider an electron that can sometimes manifest itself as a particle (1 quantum state), and sometimes it can manifest itself as a wave (2 quantum state) and apply the quantum superposition principle. To understand the principle of quantum superposition, we quote citation [3]:

"For example, consider two quantum states (actually existing) are described by wave functions ψ1 and ψ2. From the principle of superposition [1, p. 21] it should be clearly, that their linear combination (ψ3 = C1ψ1 + C2ψ2) will be the third quantum state (as actually existing), which will be described by a wave function ψ3. What does it mean? The fact that the measurement of a certain physical value d in the state |ψ1> will result d1, and for measure a value for of d in the state |ψ2> will result d2. When the third quantum state |ψ3> is realized, then when measuring a physical quantity, the quantum system will take the values d1 and d2 with probabilities, respectively, |C1|^2 and |C2|^2. That is, in a quantum state |ψ3> when we will have many dimensions sometimes d1 value and sometimes d2 (with certain known frequency)".

So let's give an analysis.

Consider an electron (or photon) that manifests itself as a particle (|ψ1> this quantum state 1, which describes an electron as a particle), then consider an electron as a wave (|ψ2> this quantum state 2, which describes an electron as a wave). Their linear combination (ψ3 = C1ψ1 + C2ψ2) will be, as usual, the third quantum state |ψ3>, which will be described by the wave function ψ3 and will describe the real elementary particle (electron, photon), a resonant hybrid (analogy with the resonance theory, also you can recall the above cube). That is, a real elementary particle (an electron or a photon) can manifest itself both as a particle (the first quantum state |ψ1>) and as a wave (the second quantum state |ψ2>). But according to the principle of quantum superposition, an elementary particle can stay in the third quantum state |ψ3> (ψ3 = C1ψ1 + C2ψ2), where it is no longer a particle and is not a wave, but a higher-order system. Hence it follows unambiguously that an elementary particle can not be regarded as a particle (a corpuscle, a small ball), and therefore its radius, coordinate, velocity, etc. characteristics can not be calculated, since this prohibits the quantum superposition principle and naturally the Heisenberg uncertainty principle, which actually strictly follows from here. At the same time, it must be remembered that the elementary particle is also not a wave.

You may ask: "What in this analysis means the value of d (more precisely, d1 and d2)?" The answer is obvious:

1) if we consider a particle (|ψ1> this quantum state 1, which describes an electron as a particle), then d1 is the kinetic energy;

2) if we regard an electron as a wave (|ψ2> this is a quantum state 2, which describes an electron as a wave), then d2 is the potential energy.

That is, the elementary particle is actually an oscillator in which the kinetic energy and potential energy transfer into each other, and when we fix the kinetic energy we register the particle (device 1), when we fix the potential energy we register the wave (device 2). From this consideration of the elementary particle, the Bohr complementarity principle (since the potential and kinetic energy completely change into one another) and the Heisenberg uncertainty principle logically follow. Here it is necessary to clarify that for the first time the hypothesis of the oscillations of elementary particles was put forward by Louis de Broglie [4, 5], but to the great regret the development of this hypothesis has not been received and almost 100 years has not been used to describe elementary particles.

Oscillation hypothesis of Louis de Broglie and wave-particle duality of elementary particles.

Louis de Broglie (French Academy) attributed a frequency of γ to each system with energy E (or mass m) using the A. Einstein equation and the M. Planck equation [5]:

"In quantum theory, I assumed that there is a periodic process associated with the electron as a whole (the material point). This process for an observer stationary relative to an electron would occur over the whole space with the same phase and would have a frequency γ = (m*c^2)/h. It could be represented for the above observer by the function like

$$\varphi(r_0)*\cos(2\pi*\gamma_0*t_0)$$

where t_0 - own time of the moving body and r_0 - distance to electron center".

Note that the Louis de Broglie oscillation hypothesis can be applied to all elementary particles, including photons.

$$E = m*c^2, \quad E = h*\gamma$$

$$E = h*\gamma = m*c^2$$

$$\gamma = (m*c^2)/h$$

Therefore, if this is applied to an electron, then we obtain an electron oscillation frequency equal to 1.236 * 10^(20) times per second:

$$\gamma_0 = (m_e c^2)/h = 1.236 \cdot 10^{20}\ \text{Hz}$$

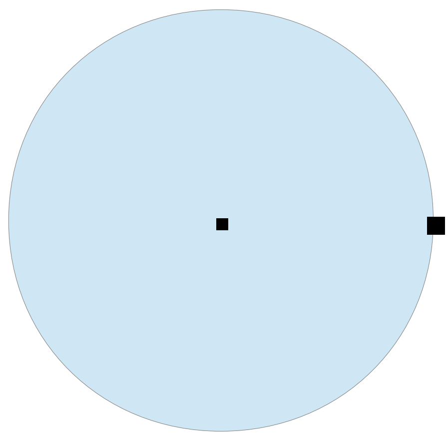
Accordingly, the electron oscillation period is 8.09*10^(-21) second:

$$\Delta T_0 = 1/\gamma_0 = h/(m_e c^2) = 8.09 \cdot 10^{-21}\ \text{s}$$

We can say that ΔT_0 = 8.09*10^(-21) s is the "time quantum of the electron" because the existence of an electron is the infinite set of these oscillations. The "time quantum of elementary particle" is important, since it is precisely its duration that will determine the behavior, energy, momentum, and other characteristics of a particle during various interactions and in various conditions. For example, when time is slowed down in black holes, an infinite lengthening of the "time quantum of a particle" occurs, which in the case of a photon leads to the impossibility of radiation of a given photon by a black hole [6].

As was shown above, in the case of oscillations of elementary particles according to de Broglie, the potential and kinetic energy of the particle interconvert with a certain frequency (for an electron, this frequency is 1.236*10^(20) Hz). But a very important conclusion follows from this: since energy cannot be transferred at a speed greater than the speed of light in a vacuum, it is natural that the periodic process associated with an electron occurs at the speed of light in a vacuum. That is, for illustrative purposes, we can imagine this periodic process as a classic rotator in which a material point moves in a circle with the speed of light in a vacuum (the mass of a material point is equal to the mass of an elementary particle).

Recall that the classic rotator is a mechanical system in which a material point or physical body rotates the relative fixed center with a certain speed. See picture.



Note that the first observer who, according to Louis de Broglie, is "stationary relative to the electron", is an observer who, in our model, moves along with the material point along a circle with the speed of light in a vacuum. This assumption is confirmed by the calculation of the length of such a circle. In fact, we calculate the wavelength, which is closed on itself along a circle, and which the observer according to de Broglie, who is "stationary relative to the electron", will see. Naturally, it is easy to understand that we get the Compton wavelength of an elementary particle. This value was received by Louis de Broglie in 1925 in his work on the electron oscillation [5, p. 205]. Let's demonstrate these calculations.

So, the speed of such a wave, as we showed above, is the speed of light in vacuum, the frequency of such a wave for an electron (or the de Broglie oscillation frequency) was also calculated earlier and is

$$\gamma_0 = (m_e c^2)/h = 1.236 \cdot 10^{20}\ \text{Hz}$$

therefore, by formula

$$\lambda = c/\gamma$$

we get the Compton electron wavelength

$$\lambda_{c.e.} = h/(m_e c) = 2.4263 \cdot 10^{-12}\ \text{m}.$$

The above calculations of the oscillation frequency and Compton wavelength of an electron were made in the same way as Louis de Broglie did in his corresponding work [4, 5]. But, to take into account the quantum nature of oscillations, it is necessary to make one essential clarification: we must consider the oscillating elementary particle as a quantum system in the ground state ("zero oscillations"). That is, oscillations at the quantum approach are the fluctuations of an elementary particle with "zero oscillations", and the energy of "zero oscillations" is calculated using the well-known formula:

$$E_0 = (h \gamma_0)/2.$$

But then, if we follow the logic of Louis de Broglie, we must $(h\gamma_0)/2$ equate with the Einstein formula divided by 2 (that is, with $(m_e c^2)/2$), otherwise the energy balance will not be maintained. As a result of this operation, we get the same values of the oscillation frequency (γ_0) and the "time quantum of electron" (ΔT_0):

$$E = m_e c^2 = h \gamma$$

$$E_0 = (h \gamma_0)/2 = (m_e c^2)/2$$

$$(h \gamma_0)/2 = (m_e c^2)/2$$

$$h*\gamma_0 = m_e*c^2$$

$$\gamma_0 = (m_e*c^2)/h$$

$$\gamma_0 = (m_e*c^2)/h = 1.236 * 10^{20}\ \text{Hz}$$

$$\Delta T_0 = 1/\gamma_0 = h/(m_e*c^2) = 8.09*10^{-21}\ \text{s}$$

What is the sense of the performed operation, if the value of the oscillation frequency turned out to be the same? The meaning is a deeper understanding of the nature of particle oscillation, which follows from this fact.

It's obvious that ½ + ½ = 1 and then

$$E = m_e*c^2 = E_0 + E_0 = (h*\gamma_0)/2 + (h*\gamma_0)/2.$$

That is, considering the oscillation of an elementary particle, we still have "two zero oscillations" (with the energy of each $E_0 = (h*\gamma_0)/2$), two matched particle oscillations that lead to the resulting oscillation. If we proceed to the wave description, then as a result of two traveling waves (more precisely, all the same two semi-waves $\lambda/2$) we get the resulting standing wave. Therefore, the wavelength, which will describe the given periodic process (this oscillation), will be twice as long as the particle's Compton wavelength:

$$\lambda_{o.} = \lambda_{c.} + \lambda_{c.}$$

$$\lambda_{o.e.} = 2*\lambda_{c.e.} = 4.8526 * 10^{-12}\ \text{m}.$$

For an electron, we obtain the value $\lambda_{o.e.} = 4.8526*10^{-12}$ m, which, as will be shown in further works, plays a fundamental role in understanding and describing chemical bonds.

For clarity, this standing wave (the resulting particle oscillation) can be represented using our classic rotator: two half-waves are moving around the circumference of the rotator through each other, at the speed of light in vacuum, each half-wave is closed around itself. It is interesting to note that, despite such a simple model, it is well representative of the process of formation of a standing wave during particle oscillations according to Louis de Broglie.

CONCLUSION.

Finally, let us summarize: the experiment with two slots clearly shows that the elementary particle (electron, photon, etc.) is not a particle or a wave, but a more complex system, in fact an oscillator (rotator-particle, "particle-oscillator" model) in which the kinetic and potential energies pass into each other with a certain frequency (and which we register as a particle and as a wave).

The period of a single oscillation of an elementary particle is an important characteristic of a given particle and determines its behavior and properties during various interactions. Since this period is a temporary period of a certain length, according to A. Einstein's theory of relativity, it can change its length, which will inevitably lead to a change in the fundamental properties of the microparticle.

Elementary particles manifest themselves if and only if the corresponding devices (by their properties) can fix their characteristics: for example, interference, when there are two slits, who "register" the spread of potential energy or a photoelectric effect, when there is a "transfer" of kinetic energy from photon to our device. Therefore, an electron, photon and other microparticles sometimes manifests itself as a particles and sometimes as a waves, but it depends only on the capabilities of the devices to register ("see") a particle or wave, that due to the internal periodic process of an elementary particle according to Louis de Broglie. The oscillation of an elementary particle is actually a "zero oscillation" of a given particle (quantum system), which can be represented as a resultant standing wave (or resultant oscillation).

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