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Article

The Hidden Noise Behind Quantum Mechanics

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Abstract: It is shown that real particles as electrons are not quantum per se. The quantum wavy character of their stochastic motion is due to force carriers transmitting the fundamental interactions. The discreteness of these relativistic quantum virtual particles as photons leads to appearance of integer quantum numbers in the solutions of the Schrödinger equation. Thus, the wave-particle dualism finally finds its rational explanation.

Keywords: quantum mechanics; stochastic interpretation; force carriers

The United Nations has declared 2025 the International Year of Quantum Science and Technology. Quantum mechanics is at present the most general theory for description of the physical World, which has replaced a century ago the Laplace determinism of classical mechanics with a probabilistic paradigm. The latter hints already that there is something behind quantum mechanics, and there are several attempts to reveal the hidden universe. One can mention here the notable contributions of de Broglie [1], Bohm [2], Nelson [3], etc. [4]. Nowadays, the best correspondence between quantum and classical mechanics is achieved via the Wigner function [5]. Using it we have demonstrated recently that quantum mechanics is due to force carriers transmitting the fundamental interactions [6]. We tried also to derive the corresponding stochastic Newton equation [6, 7], which must be able to describe the real motion of quantum particles in contrast to the probabilistic picture from the Schrödinger equation [8]. The present short paper aims to develop further our ideas by explaining stochastically more facts from the centennially celebrated quantum mechanics.

The simplest system, which is general enough to capture the whole picture, is a pair of two particles with a reduced mass μ . In the frames of quantum mechanics, its evolution is described via the Hamiltonian operator

$$\hat{H} \equiv \hat{\mathbf{p}}^2/2\mu + U(r) \quad \hat{\mathbf{p}} \equiv -i\hbar\nabla \quad (1)$$

where the potential energy U is only due to interaction between the two particles. It is evident from Eq. (1) that the complications in quantum mechanics originate from the momentum operator, which indicates some peculiarities of the particles motion. Since our goal is to explain stochastically quantum mechanics, we propose here to replace the momentum operator $\hat{\mathbf{p}}$ via a random expression $\mathbf{p} - \hbar\mathbf{q}$. The quantum fluctuation \mathbf{q} possesses zero mean value $\langle \mathbf{q} \rangle = 0$ and plays the role of a stochastic wave vector, which causes now the probabilistic nature of quantum mechanics [9, 10]. The Standard Model explains the classical static scalar potentials as transmitted via quantum force carriers, e.g. gauge bosons [11]. Apart from the necessary energy, these virtual particles possess other properties such as momentum, spin, etc., which are not entirely comprised in U . Naturally, the complete description of the force carriers is provided by their wave function, which is known to be a quantum vector potential [11]. Because we do not know the latter, we model it stochastically via $\hbar\mathbf{q}$, which can be termed as an unobservable Berry potential [12]. Force carriers are transverse waves in configurational space, traveling between the real particles, and for this reason the stochastic vector potential is always tangential, i.e. $\mathbf{q} \cdot \mathbf{r} = 0$. In the non-relativistic case, which assumes instant exchange of force carriers, $\mathbf{q}(\mathbf{r})$ does not depend explicitly on time, but it is a random function of the positions of the real particles.

According to the picture above, the real particles are classical, while quantum effects are due to the wavy force carriers, which are the only reason for appearance of the Planck constant \hbar as well. The stochastic Hamilton function corresponding to the Hamiltonian operator (1) reads

$$H = (\mathbf{p} - \hbar\mathbf{q})^2/2\mu + U(r) \quad (2)$$

and it reduces to the non-stochastic classical expression at $\hbar = 0$. The Hamilton function (2) determines completely the motion of the target particles via the well-known Hamilton equations

$$\dot{\mathbf{r}} = \partial H/\partial \mathbf{p} \quad \dot{\mathbf{p}} = -\partial H/\partial \mathbf{r} \quad (3)$$

The first kinematic equation relates the momentum $\mathbf{p} = \mu\mathbf{v} + \hbar\mathbf{q}$ to the velocity $\mathbf{v} \equiv \dot{\mathbf{r}}$. Obviously, this expression satisfies the Ehrenfest theorem $\langle \mathbf{p} \rangle = \langle \mu\mathbf{v} \rangle$ known in quantum mechanics. Substituting the momentum in the second dynamic equation (3) yields a stochastic Newton equation

$$\mu\dot{\mathbf{v}} = -\nabla U + \mathbf{f} \quad \mathbf{f} \equiv \mathbf{v} \times (\hbar\nabla \times \mathbf{q}) \quad (4)$$

where $\nabla \equiv \partial/\partial \mathbf{r}$ is the nabla operator. The random force \mathbf{f} looks like a stochastic Lorentz force, which supports the Schwinger viewpoint on the magnetic origin of quantum mechanics [13]. The other part $\langle \mu\dot{\mathbf{v}} \rangle = -\langle \nabla U \rangle$ of the Ehrenfest theorem requires that $\langle \mathbf{f} \rangle = 0$. Since the stochastic force is orthogonal to the velocity, $\mathbf{f} \cdot \mathbf{v} = 0$ allows direct integration of Eq. (4) to obtain energy as an integral of motion, $E = \mu v^2/2 + U$. Therefore, quantum fluctuation \mathbf{q} preserves particles energy at any time, $\dot{E} = 0$, because force carrier energy is already comprised in the potential U . The particles energy can be derived also via direct substitution of the momentum in Eq. (2), since $H = E$.

The change of description from the abstract momentum to the real velocity is related to transition from the Hamiltonian (2) to the Lagrangian $\mathcal{L} \equiv \mathbf{p} \cdot \mathbf{v} - H = \mu v^2/2 - U + \hbar\mathbf{q} \cdot \mathbf{v}$. Hence, $\mathbf{p} \equiv \partial \mathcal{L}/\partial \mathbf{v} = \mu\mathbf{v} + \hbar\mathbf{q}$ and its evolution is governed via $\dot{\mathbf{p}} = \partial \mathcal{L}/\partial \mathbf{r}$, which coincides with Eq. (3). Because $\mathbf{q} \cdot \mathbf{r} = 0$, the last term in the Lagrangian depends only on the tangential velocity $\boldsymbol{\omega} \times \mathbf{r}$, where the angular velocity reads $\boldsymbol{\omega} \equiv \mathbf{r} \times \mathbf{v}/r^2$. Thus, the Lagrangian acquires a more transparent form $\mathcal{L} = \mu v^2/2 - U + \hbar\boldsymbol{\omega} \cdot \mathbf{m}$, which accounts for exchange of energy quanta with proper resonant frequencies. The vector $\mathbf{m} \equiv \mathbf{r} \times \mathbf{q}$ is obviously dimensionless angular momentum of quantum fluctuations. Since its modulus $m = qr$ is a wave number, which counts the number of wave nodes, it must be proportional to the radial quantum number. Furthermore, the total angular momentum reads

$$\mathbf{L} \equiv \mathbf{r} \times \mathbf{p} = \mu r^2 \boldsymbol{\omega} + \hbar \mathbf{m} \quad (5)$$

Differentiating \mathbf{L} on time by employing Eq. (3) yields a stochastic torque equation

$$\dot{\mathbf{L}} = \hbar \mathbf{v} \times \mathbf{q} \quad (6)$$

As is seen, the angular velocity is constant in classical mechanics ($\hbar = 0$) and the 2D trajectory of the particles lies on a plane perpendicular to $\boldsymbol{\omega}$. This feature of the Bohr-Sommerfeld quantum model as well contradicts to the 3D orbitales derived from the Schrödinger equation, which could be now explained by Eq. (6). Integration of the latter yields the angular momentum of the particles

$$\mathbf{L} = \hbar \int d\mathbf{r} \times \mathbf{q} \equiv \hbar \mathbf{s} \quad (7)$$

Amazingly, the angular momentum just replicates the spin angular momentum (SAM) of force carriers. Hence, \mathbf{L} is entirely generated by the discrete quanta of force carriers and, since the latter are quantum particles, the integration in Eq. (7) must be equivalent to quantum mechanical averaging. Because the spin of a single carrier is $\pm\hbar$, the components of the vector \mathbf{s} are integers, counting the number of exchanged virtual particles with different polarizations. In contrast to standard quantum considerations, however, the magnetic quantum numbers s_i are considered random here. Since they do not affect energy, s_i is uniformly distributed in a symmetrically bounded range $[-l, l]$ with $2l + 1$ possible realizations. The average value $\langle \mathbf{L} \rangle = 0$ reflects clearly $\langle \mathbf{q} \rangle = 0$. One can calculate also the dispersion of the angular momentum $\langle L^2 \rangle = 3 \langle s_i^2 \rangle = \hbar^2 = l(l+1)\hbar^2$, which corresponds to the well-known quantum mechanical expression. The azimuthal quantum number $l = 0, 1, \dots$ appears here as the upper bound of the s_i distribution but

it is also the spin quantum number of SAM. As is seen, the magnetic and azimuthal quantum numbers, usually derived from the Schrödinger equation, are simply integers due to the discreteness of quantum force carriers.

It is easy to obtain the angular velocity from Eqs. (5) and (7)

$$\mu r^2 \boldsymbol{\omega} = \hbar(\mathbf{s} - \mathbf{m}) = \hbar \int d\mathbf{q} \times \mathbf{r} \equiv -\hbar \mathbf{n} \quad (8)$$

which appears to be completely generated by the orbital angular momentum (OAM) of force carriers. While the systematic rotations around \mathbf{L} vanish at $l = 0$, the stochastic revolutions around $\boldsymbol{\omega}$ persist forever because $\mathbf{n} \neq 0$ but anyway $\langle \mathbf{n} \rangle = 0$. For example, the random tangential velocity $\boldsymbol{\omega} \times \mathbf{r}$ in s-orbitals is just the specific quantum fluctuation $-\hbar \mathbf{q}/\mu$, because the tangential momentum is zero. The OAM quantization requires that the random components of the vector \mathbf{n} are integers, being the so-called topological charges. The topological quantum numbers n_i determine the helical structure of the wave front [14] of force carriers, which reflects in the radial nodes in quantum mechanics as well. Therefore, Eq. (8) represents a stochastic Bohr quantization rule [15]. OAM and SAM fluctuations are not independent since they are related by Eq. (8) via the total angular momentum of the force carriers $\mathbf{m} = \mathbf{n} + \mathbf{s}$. Hence, the latter is quantized as well, while the Lagrangian acquires the alternative form $\mathcal{L} = \mu v^2/2 - U + (s^2 - n^2 - m^2)\hbar^2/2\mu r^2$ by employing Eq. (8). As was mentioned before, m leads to the radial quantum number, which is always proportional to the difference of the principal and azimuthal quantum numbers.

What remains unclear yet is the most important problem regarding the radial motion of the target particles, which depends on the potential U . Substituting the velocity $\mathbf{v} = \dot{r}\mathbf{r}/r - \hbar \mathbf{n} \times \mathbf{r}/\mu r^2$ in the energy leads to

$$E = \mu \dot{r}^2/2 + n^2 \hbar^2/2\mu r^2 + U(r) \quad (9)$$

Because energy is constant, one can standardly obtain from Eq. (9) a stochastic equation for the radial motion

$$\mu r \dot{r} = \pm \sqrt{2\mu r^2(E - U) - n^2 \hbar^2} \quad (10)$$

It describes a nonlinear stochastic oscillator, where the random integer $n(r)$ represents the effect of the quantum fluctuation \mathbf{q} . Furthermore, the momentum reads $\mathbf{p} = \mu \dot{r}\mathbf{r}/r + \hbar \mathbf{s} \times \mathbf{r}/r^2$.

It is useful to average Eq. (11) over time to obtain $\pm \sqrt{2\mu r^2(E - U) - n^2 \hbar^2} = 0$. According to the mean value theorem for integrals in mathematics, there is at least one inner point R , where the expression under the root is zero. Hence, the particles energy acquires the form

$$E = \bar{n}^2 \hbar^2/2\mu R^2 + U(R) \quad (11)$$

where $\bar{n} = n(R)$ is the principal quantum number. Applying the mean value theorem to the virial theorem $\overline{\mu v^2} = r \overline{U'}$, which is valid in quantum mechanics as well, yields the local force balance

$$U'(R) = \bar{n}^2 \hbar^2/\mu R^3 \quad (12)$$

Note that Eq. (12) implies minimal energy, because $\partial E/\partial R = 0$. There are only two potentials, the energy of which depends solely on the principal quantum number, but they are extremely important. Considering a hydrogen atom with potential $U = -e^2/r$, the well-known expressions $R = \bar{n}^2 \hbar^2/\mu e^2$ and $E = -\mu e^4/2\hbar^2 \bar{n}^2$ follow from Eqs. (12) and (11), respectively, which were derived by Bohr first [15]. Alternatively, $R^2 = \bar{n}\hbar/\mu\omega_0$ follows from Eq. (12) for a 3D isotropic harmonic oscillator with the potential $U = \mu\omega_0^2 r^2/2$, while the energy $E = \bar{n}\hbar\omega_0$ corresponding from Eq. (11) equals to the expected quantum result. Finally, one can trace the roots of our hypothesis back to the Schrödinger equation in momentum representation

$$i\hbar \partial \psi / \partial t = p^2 \psi / 2\mu + \int \tilde{U}(q) \psi(\mathbf{p} - \hbar \mathbf{q}, t) d^3 \mathbf{q} \quad (13)$$

where $\psi(\mathbf{p}, t)$ is the corresponding wave function. Looking at the last collisional integral one can recognize that the Fourier image $\tilde{U}(q)$ of the interaction potential $U(r)$ must be related to the density of force carriers [6]. Indeed, according to quantum field theory [11] \tilde{U} is proportional to the Feynman propagator of virtual particles.

In conclusion, it is shown in the present paper that real particles as electrons are not quantum per se. The wavy quantum character of their stochastic motion is due to force carriers transmitting fundamental interactions. Interference of the latter is clearly seen in double slit experiments. Thus, the wave-particle duality finally finds its rational explanation. The discreteness of relativistic quantum force carriers leads to appearance of integer quantum numbers in the solutions of the Schrödinger equation. One can argue the validity of our theory for the case of free particles, where $U \equiv 0$ implies lack of any force carriers. Hence, a particle must move classically with a constant velocity. However, to fix the particle at its initial position one must apply a strong potential at the beginning. Force carriers of the latter will randomize the initial coordinates and momenta of the particle [6]. Thus, the particle will move freely later but with stochastic initial conditions and this is exactly what is known in quantum mechanics as the spreading of a Gaussian wave packet, for instance.

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