

# Quantum mechanics emerging from stochastic dynamics of virtual particles

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**Abstract.** It is shown how quantum mechanics emerges from the stochastic dynamics of force carriers. It is demonstrated that the Moyal equation corresponds to dynamic correlations between the real particle momentum and the virtual particle position, which are not present in classical mechanics. This new concept throws light on the physical meaning of quantum theory, showing that the Planck constant square is a second-second position-momentum cross-cumulant.

According to modern physics, the Newtonian interactions in classical mechanics occur via exchange of force carriers [1]. These virtual particles transmit the long-range interactions among the real particles and interact only locally with the latter. Generally, it is expected that the force carriers dynamics is stochastic, which will result in random Newtonian potentials. Thus, the stochastic motion of the virtual particles can cause quantum dynamics [2]. Stochastic electrodynamics is an important example, for instance, which is already proposed as an origin of quantum mechanics [3]. In the present paper it is shown how quantum mechanics emerges from the stochastic dynamics of force carriers [4]. It is also demonstrated that the quantum Moyal equation [5] corresponds to statistical correlations between the real particle momentum and the virtual particle position, not present in classical mechanics. The model throws light on the physical meaning of the Planck constant, a quintessence of quantum theory.

Let us consider first a real and a virtual particles, located at positions  $r$  and  $R$ , respectively. Since by definition there is no long-range forces, their interaction is a delta-potential  $\varepsilon\delta(r - R)$ . The specific parameter  $\varepsilon$  accounts for the type of interaction, e.g. electrostatic, gravitational, etc. In general, the position of the virtual particle is expected to be random and, hence, the interaction potential above is a stochastic one [4]. The corresponding force, acting on the real particle, reads  $-\varepsilon\partial_r\delta(r - R)$ . Introducing the real particle phase-space distribution density  $W(p, r, t)$ , one can write its dynamics in the form

$$\partial_t W + p \cdot \partial_r W / m = \partial_p \cdot \int_{-\infty}^{\infty} \varepsilon \partial_r \delta(r - R) F(R, p, r, t) dR = \partial_p \cdot (\varepsilon \partial_R F)_{R=r} \quad (1)$$

The interaction between the real and virtual particles is expressed in Eq. (1) via a collision integral, where  $F(R, p, r, t)$  is the joint probability density for the virtual particle to occupy the position  $R$  and for the real particle to have momentum  $p$  and coordinate  $r$  at time  $t$ . The real particle marginal probability density  $W$  can be derived from  $F$  via a simple integration over  $R$

$$W(p, r, t) \equiv \int_{-\infty}^{\infty} F(R, p, r, t) dR \quad \rho(R, t) \equiv \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(R, p, r, t) dp dr \quad (2)$$



while  $\rho(R, t)$  is the local density of force carriers. A macro-particle interacts with many force carriers at once and thus stochastic forces cancel each other. This results in classical mechanics, where the virtual particle distribution is independent of the real particle. Hence, the joint probability density factorizes in a product  $F(R, p, r, t) = \rho(R, t)W(p, r, t)$  of the virtual particle density and the real particle probability density. In this case Eq. (1) reduces straightforward to the Liouville equation from classical dynamics

$$\partial_t W + p \cdot \partial_r W / m = \partial_r U \cdot \partial_p W \quad U(r, t) = \int_{-\infty}^{\infty} \varepsilon \delta(r - R) \rho(R, t) dR = \varepsilon \rho(r, t) \quad (3)$$

The corresponding Newtonian potential  $U$  follows exactly the distribution of the virtual particles in the system, which is not perturbed by the motion of the real particle. There are indications in quantum mechanics that the real particle motion affects the distribution of virtual particles. The Liouville equation (3) changes to the Wigner–Liouville or Moyal equation

$$\partial_t W + p \cdot \partial_r W / m = \sum_{n=0}^{\infty} \frac{(i\hbar/2)^{2n}}{(2n+1)!} \partial_r^{2n+1} U \cdot \partial_p^{2n+1} W \quad (4)$$

Keeping in mind the definition of the Newtonian potential  $U = \varepsilon \rho$ , the juxtaposition of the Wigner–Liouville equation (4) and Eq. (1) unveils a possible expression for the joint distribution density

$$F(R, p, r, t) = \rho W + \sum_{n=1}^{\infty} \frac{(i\hbar/2)^{2n}}{(2n+1)!} \partial_R^{2n} \rho \cdot \partial_p^{2n} W \quad (5)$$

As is seen, the last sum represents a correlation function between the virtual and real particles, which vanishes in the classical limit at  $\hbar \rightarrow 0$ . The analysis of the probability density (5) is easier in the Fourier space, where the corresponding characteristic function is given by

$$\tilde{F}(K, q, k, t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \exp(iK \cdot R + iq \cdot p + ik \cdot r) F(R, p, r, t) dR dp dr \quad (6)$$

Substituting here Eq. (5) yields the characteristic function

$$\tilde{F}(K, q, k, t) = \tilde{\rho}(K, t) \frac{\sin(\hbar K \cdot q/2)}{\hbar K \cdot q/2} \tilde{W}(q, k, t) \quad (7)$$

expressed by the characteristic functions of the marginal distributions (2). The corresponding generating function of the cross-cumulant of the real particle momentum and the force carrier position reads

$$\Phi \equiv \ln \frac{\tilde{F}(K, q, k, t)}{\tilde{\rho}(K, t) \tilde{W}(q, k, t)} = \ln \frac{\sin(\hbar K \cdot q/2)}{\hbar K \cdot q/2} \quad (8)$$

As is seen,  $\Phi$  is independent of time and of the real particle position. Hence, quantum mechanics is due to disturbances of the virtual particle sea caused by the real particle motion. The only parameter in  $\Phi$  is the Planck constant  $\hbar$  and Eq. (8) can elucidate its physical meaning. The expansion in power series  $\Phi = -(\hbar K \cdot q)^2/24 + \dots$  shows that the second-second cross-cumulant of the virtual particle position and the real particle momentum equals to  $\kappa_{22} \equiv \langle (r \cdot p)^2 \rangle - \langle R \otimes R \rangle : \langle p \otimes p \rangle = -\hbar^2/2$ . It indicates a firm anti-correlation between the virtual particle position and the real particle momentum. In contrast to the famous Heisenberg inequality  $\sigma_r \sigma_p \geq \hbar/2$ , restricting the real particle momentum and position,  $\hbar^2 = -2\kappa_{22}$  is an equality which could be considered as the Planck constant definition. A new Heisenberg relation  $\sigma_{R^2} \sigma_{p^2} \geq \hbar^2/2$  follows from the Cauchy-Schwarz inequality  $\kappa_{22} \geq -\sigma_{R^2} \sigma_{p^2}$ .

## References

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