Mini Review

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Local/nonlocal descriptions in physics and dimension of space

Abstract

Over the past 100 years, great progress has been made in describing the microworld in the local approach. Nevertheless, there are serious reasons to believe that real interactions in nature are not local. Whether the interactions are local or not is not simply a question of describing or reflecting the reality that we observe. The nonlocal nature of interactions dictates the necessity of having a certain dimensionality of space. Thus, nonlocality of interactions entails restrictions on the dimensionality of our space connecting together the micro and the macro phenomena.

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Introduction

From the end of the 19th century, the accumulation of results that did not fit into the old classical ideas began. Their understanding led to the birth of quantum mechanics, which makes it possible to give reasonable explanations for the phenomena of the microworld. Its birth can be considered since 1900, when M. Planck gave an explanation of the radiation of an absolutely black body. Its final formation took place in 1925-1927. So, about 100 years have passed since her birth. What can we say at the moment about the nature of our world-the world in which we exist and surround us?

Local description

Significant advances in the physics are associated with the use of Lagrangian functions with local density. The Lagrange function (Lagrangian) or its density is determined on spatial structures, the simplest of which is the point of space. Such Lagrange functions are called local. In the local approach, the overwhelming number of results known to us is obtained. Strange results of experiments of the microworld, which did not lend itself to a classical explanation, led W. Heisenberg first to the matrix formulation of quantum mechanics.[1,2] During the discussion of this formulation by M. Born, W. Heisenberg and other theoretical physicists from Göttingen with D. Hilbert, the latter noted that such a structure of relations arises from the boundary problem conditions of differential equations and advised to look for a differential equation. In addition to Hilbert, according to E. Condon's memories, no one seemed to understand what he was talking about.[3] But the equation soon really appeared–the Schrödinger equation.[1–4] With the advent of the Schrödinger equation (wave equation), the period of the formation of quantum mechanics was ended. In the local approach L. de Broglie from the analogy of the description of particles in classical mechanics and the wave motion of light, concludes that massive as well as massless particles, should exhibit wave properties and obtain a relation connecting the momentum of a particle with its wavelength.[4] Further development of the local approach led to phenomenal results. For example, the theoretical value of the anomalous magnetic moment of an electron in relativistic quantum electrodynamics coincides with the experimental value with an accuracy of up to 11 significant digits (relative accuracy of 2×10^{-10}).[5–8]

Non-local description

In local description the Lagrangian is determined on the points of space. Using theories with local Lagrange functions greatly simplifies the analysis, but it does not follow from anywhere that it is the only possible physical theories. The object following on complexity after a point is the one dimensional structure –the lines on which Lagrange's function is defined, are called strings, the main emphasis of research with nonlocal Lagrangians is still focused on the consideration of strings. Corresponding theories are called string theories.[9–12] Basically, optimism when considering string theory is related to the fact that this approach can lead to quantization of gravity. Note that while all the advantages of string theory remain without experimental confirmation. Nevertheless, this approach is undoubtedly also necessary to be developed, in order to understand the opportunities in the description of the real world. Thanks to the local description, we have achieved a significant advance in understanding the phenomena of the microworld. But does this support the local nature of interactions in nature? Apparently not. What are the evidences of the nonlocality of interactions?

Probabilistic description

The developed apparatus of quantum mechanics deals with wave functions. But the approach based on the use of wave functions is related to the probability description. We can only predict the probabilities of the processes that are taking place. This in itself already suggests that we cannot talk about exact localization, for example, the position and momentum of a particle, this circumstance may be due precisely to its nonlocality or its nonlocal interaction with the environment.

The Heisenberg uncertainty relations

Indeed, as a consequence of a probabilistic description, we receive at the Heisenberg uncertainty relations.[1,2,4,13] The impossibility of an

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accurate prediction of the characteristics of a particle, it is natural to associate with the fact that it does not represent a local object.

Noncommutativity of operators

A reflection of the uncertainty relations in the apparatus of quantum mechanics is the noncommutativity of the operators of conjugate physical quantities. One of the developments of this approach was a description in the framework of a nonassociative theory.[14]

Path integrals

The nonlocality of processes in the microworld is also evidenced by one of the formulations of the quantum theory, in which the description of the behavior of a system requires knowledge of its interaction, taking into account all its possible positions, a theory based on path integrals.[15] In this case, the system does not simply move in the optimal way in a certain phase trajectory, as in the classical variational principle, but it instantly participates in all its possible developmental histories.

Corpuscular-wave dualism

The fact that the system participates in all its possible realizations is reflected in the corpuscular-wave dualism. This is one of the brightest manifestations of nonlocality. For example, in interference experiments on particles scattering on slits, particles feel at once both (or all, if there are more than two) slits. An attempt to describe these experiments according to the local nature of particles does not lead to an explanation of the observed effects. Conducting ingenious experiments that seemingly should "force" photons or particles to behave locally-experiments on the interference of single particles, experiments on anticoincidence, experiments with deferred choice, etc., each time lead to the opposite situation. Particles can not be deceived. They feel all their possible positions and participate in them and do not succumb to the provocation of these ingenious experiments.[16]

Relationship between the wave nature of particles and the nature of the Heisenberg uncertainty relations

As noted above, the uncertainty relations are a serious argument in favor of the nonlocality of microworld processes. We note that in the overwhelming number of attempts to disprove the uncertainty relations, for example, in Bohr's disputes with Einstein (see also the supplement to the Russian edition[1]), thought experiments with light exhibiting wave properties took place. This suggests that the wave nature of photons (or massive particles) is closely related to the nature of the uncertainty relation. If the uncertainty relations are a consequence of non-locality, then the wave structure of particles (both mass and massless) should be also described in a nonlocal way. Indeed, it can be shown that the both wave nature of particles and the nature of uncertainty relations can be explained in a nonlocal approach.[17]

Dimension of space

The problem of non-locality in quantum mechanics led to a consideration of a nonlocal description of micro phenomena. This consideration, in particular, led to the construction of nonlocal Lagrangians, or in other words to the construction of a string theory. In this theory, space cannot have an arbitrary dimension-the dimension is determined by commutation relations for the generators of Lorentz charges.[9–11] The laws of symmetry of string theory applied to the initial moment of the Big Bang (BB) theory lead to an infinite dimensionality of space

$$N(t)^3\, 16\pi^3 a'^2 w(t),$$

where a' is so called slope parameter in string theory, which is proportional to the string tension, and $w(t)$ is an energy density of BB at some time moment t near BB initiation, and, consequently, to the possibility of changing it.[18,19] The change in the dimension of space gives, in turn, the key to describing the nature of the cosmological constant.[18,19] Thus, the phenomena of micro- and macrocosm are connected in a non-trivial way.

Conclusion

Over the past 100 years since the birth of quantum mechanics, significant progress has been made in understanding the phenomena of the micro world. Such advancement is carried out due to the application of the local apparatus of the theory. However, the totality of the obtained data indicates that the processes occurring in the microworld are most likely nonlocal. The nonlocal nature of the processes of the microworld connects us with a space of a certain dimension. Thus, the fact of the "strange" behavior of microworld objects from the point of view of the classical description gives us a hint about the dimension of the space in which we are located and is, apparently, the first historical evidence of this. Or, in other words, the nonlocality of the processes of the microworld is evidence that the dimensionality of the space in which we are located can not be arbitrary, but is a quite definite value, which at the current stage of development of our Universe, most likely, according to string theory, that is the simplest description of nonlocality, cannot be less than.[11] In addition, the non-local phenomena of the micro world have led not only to the understanding that the surrounding space is multidimensional. The multidimensionality of space and the possibility of changing its dimension shed light on the possible origin of the cosmological constant. Thus, the phenomena of micro- and macrocosm are closely interrelated.

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Conflicts of interest

Author declares that there is no conflict of interest.

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