Does relativity lie at the source of quantum exoticism?

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The evolution of probabilities and the "impossible" phenomena of quantum mechanics may have their origins in the special theory of relativity, as suggested by physicists from universities in Warsaw and Oxford. Credit: FUW

Since its beginnings, quantum mechanics hasn't ceased to amaze us with its peculiarity, so difficult to understand. Why does one particle seem to pass through two slits simultaneously? Why, instead of specific predictions, can we only talk about evolution of probabilities? According to theorists from universities in Warsaw and Oxford, the most important features of the quantum world may result from the special theory of relativity, which until now seemed to have little to do with quantum mechanics.

Since the arrival of quantum mechanics and the theory of relativity, physicists have lost sleep over the incompatibility of these three concepts (three, since there are two theories of relativity: special and general). It has commonly been accepted that it is the description of quantum mechanics that is the more fundamental and that the theory of relativity that will have to be adjusted to it. Dr. Andrzej Dragan from the Faculty of Physics, University of Warsaw (FUW) and Prof. Artur Ekert from the University of Oxford (UO) have just presented their reasoning leading to a different conclusion. In the article "The Quantum Principle of Relativity," published in the *New Journal of Physics*, they prove that the features of quantum mechanics determining its uniqueness and its non-intuitive exoticism—accepted, what's more, on faith (as axioms)—can be explained within the framework of the special theory of relativity. One only has to decide on a certain rather unorthodox step.

Albert Einstein based the special theory of relativity on two postulates. The first is known as the Galilean principle of relativity (which, please note, is a special case of the Copernican principle). This states that physics is the same in every inertial system (i.e., one that is either at rest or in a steady straight line motion). The second postulate, formulated on the result of the famous Michelson-Morley experiment, imposed the requirement of a constant velocity of light in every reference system.

"Einstein considered the second postulate to be crucial. In reality, what is crucial is the principle of relativity. Already in 1910 Vladimir Ignatowski showed that based only on this principle it is possible to reconstruct all relativistic phenomena of the special theory of relativity. A strikingly simple reasoning, leading directly from the principle of relativity to relativism, was also presented in 1992 by Professor Andrzej Szymacha from our faculty," says Dr. Dragan.

The special theory of relativity is a coherent structure that allows for three mathematically correct types of solutions: a world of particles moving at subluminal velocities, a world of particles moving at the velocity of light and a world of particles moving at superluminal velocities. This third option has always been rejected as having nothing to do with reality.

"We posed the question: what happens if—for the time being without entering into the physicality or non-physicality of the solutions—we take seriously not part of the special theory of relativity, but all of it, together with the superluminal system? We expected cause-effect paradoxes. Meanwhile, we saw exactly those effects that form the deepest core of quantum mechanics," say Dr. Dragan and Prof. Ekert.

Initially, both theorists considered a simplified case: space-time with all three families of solutions, but consisting of only one spatial and one time dimension (1+1). A particle at rest in one system of solutions seems to move superluminally in the other, which means that superluminosity itself is relative.

In a space-time continuum constructed this way, non-deterministic events occur naturally. If in one system at point A there is generation of a superluminal particle, even completely predictable, emitted towards point B, where there is simply no information about the reasons for the emission, then from the point of view of the observer in the second system events run from point B to point A, so they start from a completely unpredictable event. It turns out that analogous effects appear also in the case of subluminal particle emissions.

Both theorists have also shown that after taking into account superluminal solutions, the motion of a particle on multiple trajectories simultaneously appears naturally, and a description of the course of events requires the introduction of a sum of combined amplitudes of probability that indicate the existence of superposition of states, a phenomenon thus far associated only with quantum mechanics.

In the case of space-time with three spatial dimensions and one time dimension (3+1), that is, corresponding to our physical reality, the situation is more complicated. The principle of relativity in its original form is not preserved—the subluminal and superluminal systems are distinguishable. However, the researchers noticed that when the principle of relativity is modified to the form: "The ability to describe an event in a local and deterministic way should not depend on the choice of an inertial reference system," it limits the solutions to those in which all the conclusions from the consideration in (1+1) space-time remain valid.

"We noticed, incidentally, the possibility of an interesting interpretation of the role of individual dimensions. In the system that looks superluminal to the observer some space-time dimensions seem to change their physical roles. Only one dimension of superluminal light has a spatial character—the one along which the particle moves. The other three dimensions appear to be time dimensions," says Dr. Dragan.

A characteristic feature of spatial dimensions is that a particle can move in any direction or remain at rest, while in a time dimension it always propagates in one direction (what we call aging in everyday language). So, three time dimensions of the superluminal system with one spatial dimension (1+3) would thus mean that particles inevitably age in three times simultaneously. The ageing process of a particle in a superluminal system (1+3), observed from a subluminal system (3+1), would look as if the particle was moving like a spherical wave, leading to the famous Huygens principle (every point on a wavefront can be treated itself as a source of a new spherical wave) and corpuscular-wave dualism.

"All the strangeness that appears when considering solutions relating to a system that looks superluminal turns out to be no stranger than what commonly accepted and experimentally verified quantum theory has long been saying. On the contrary, taking into account a superluminal system, it is possible—at least theoretically—to derive some of the postulates of quantum mechanics from the special theory of relativity, which were usually accepted as not resulting from other, more fundamental reasons," Dr. Dragan concludes.

For almost a hundred years quantum mechanics has been awaiting a deeper theory to explain the nature of its mysterious phenomena. If the reasoning presented by the physicists from FUW and UO stands the test of time, history would cruelly mock all physicists. The "unknown" theory sought for decades, explaining the uniqueness of quantum mechanics, would be something already known from the very first work on quantum theory.

More information: Andrzej Dragan et al, Quantum principle of relativity, *New Journal of Physics* (2020). DOI: 10.1088/1367-2630/ab76f7

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