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Where is it, the foundation of quantum reality?

With the aid of simple theoretical models it is possible to build systems operating strictly according to the rules of classical physics, yet faithfully reproducing the predictions of quantum mechanics for single particles – even those that are the most paradoxical! So what is the real hallmark of quantum behaviour?

The world of quantum phenomena is full of paradoxes incomprehensible to human intuition and inexplicable to classical physics. This is the thesis we almost always hear when it comes to quantum mechanics. Here are some examples of phenomena that are commonly considered to be typically quantum: a single electron generating interference fringes behind two slits, as if it were passing through both at the same time; particles that are in different states at the same time, only to appear "magically" in one selected state at the moment of observation; measurements without interactions; erasing the past by means of a quantum eraser; or finally, nonlocality, which gives the impression that entangled particles are immediately interacting over any long distance. But do all these phenomena necessarily have to be purely quantum?

In an article that has just been published, Dr. Pawel Blasiak from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow showed how to construct, from the building blocks of classical physics, broadly understood optical interferometric systems, faithfully reproducing the strangest predictions of quantum for single particles. The presented model helps us to understand better why quantum mechanics is needed and what it really tells us about our surrounding reality that is new. If a quantum effect has a simple classical explanation, one should not go looking for any particular secret in it. The publication clearly indicates the boundary beyond which quantum theory becomes essential: true quantum "magic" only starts with multiple particles.

"There's a lot of controversy around quantum mechanics. It's so strong that even today, when this theory is almost a hundred years old, most physicists prefer just to use it, avoiding uncomfortable questions about interpretation," says Dr. Blasiak, and adds: "Our problems here result from the fact that.... we have been too determined. Earlier on, first of all we would observe certain phenomena and, in order to explain them, construct a mathematical apparatus on the basis of well-established physical intuition. In the case of quantum mechanics, the opposite has happened: from only a few experimental clues we have guessed a highly abstract, mathematical formalism that describes the results of laboratory measurements very well, but we haven't a clue about what the physical reality lying behind it is."

Richard Feynman, the outstanding American physicist, was deeply convinced that one phenomenon absolutely impossible to explain by classical physics is quantum interference, responsible, among other things, for the fringes visible behind two slits through which a single quantum object passes. Erwin Schrödinger, one of the fathers of quantum mechanics, had a different favourite: quantum entanglement, which can at a distance bind the characteristics of two or more quantum particles. A large group of physicists is still wondering to what extent these non-intuitive phenomena of quantum mechanics are just the result of our cognitive limitations, i.e. the ways in which we study the world. Not nature, but our lack of full knowledge about the system would cause the phenomena observed in it to acquire the features of unexplainable exoticism. This type of approach is an attempt to look at quantum mechanics as a theory with a well-defined ontology, leading to the question of what really distinguishes quantum theory from classical theories.

The article in *Physical Review A* demonstrated the principles of constructing models of any complex optical systems built of elements functioning according to the principles of classical physics with the addition of certain local hidden variables, to which we have only indirect access. Dr. Blasiak showed that for single particles, the presented model faithfully reproduces all the phenomena commonly regarded as an obvious sign of quantum behaviour, including collapse of the wave function, quantum interference and contextuality. Moreover, the classical analogies of these phenomena turn out to be quite simple. However, this model cannot reproduce the characteristic features of quantum entanglement, the occurrence of which requires at least two quantum particles. This seems to indicate that entanglement and the associated nonlocality may be a more fundamental property of the quantum world than quantum interference.

“This type of approach allows us to avoid the terrible practice of evasive answers and waving our hands around in discussions about the fundamentals and interpretation of quantum mechanics. We have the tools to formulate such questions and solve them precisely. The constructed model aims to show that ontological models with limited access to information have at least the potential possibility of explaining most of the exotic quantum phenomena within broadly understood classical physics. The only real quantum mystery to remain would be quantum entanglement,” explains Dr. Blasiak.

Quantum entanglement thus gets to the core of quantum mechanics, indicating the “something” that forces a departure from classically understood reality and shifts the border of mystery towards multi-particle phenomena. It turns out that quantum effects for single particles can be successfully reproduced within classical (i.e. local) ontological models with limited access to information. So if we leave out multi-particle phenomena, we could basically do without quantum mechanics and its “spooky” nonlocality. The described local model, reproducing quantum phenomena for a single particle, very clearly defines the limit beyond which statements concerning nonlocality lose their legitimacy.

So, Feynman or Schrödinger? Schrödinger seems to have got to the very heart of quantum mechanics. But the silent winner could be... Albert Einstein, who was never satisfied with the commonly accepted interpretation of quantum mechanics. Without his stubborn questions we would have neither Bell's theorem nor the field of quantum information today.

“That's why research into the fundations of quantum mechanics is so fascinating. It ranges from recurring questions about the nature of our reality to the essence of real quantum behaviour, to which we owe the advantage quantum technologies have over their classical equivalents,” concludes Dr. Blasiak with a smile.

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SCIENTIFIC PAPERS:

1. “Local model of a qudit: Single particle in optical circuits”
P. Błasiak
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http://www.ifj.edu.pl/
The website of the Institute of Nuclear Physics Polish Academy of Sciences.

http://press.ifj.edu.pl/
Press releases of the Institute of Nuclear Physics Polish Academy of Sciences.

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Entanglement or quantum interference? – that is the question about the foundation of quantum reality! (Source: IFJ PAN)