Review of: "On Quantum Superposition"

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My first impression when reading Guang-Liang Li's *On Quantum Superposition*[1] on his theory of an unattainability of precise coordinates, was: yet another interpretation of quantum theory which misses the point, pulls an interpretation out of the hat, and repeats the dogma of Albert Einstein's article *Quantum Mechanics and Reality*,[2] published in 1948. Einstein was known to reject quantum theory, and I was stunned to read that the author of an article on Quantum Superposition agrees with this rejection. Well, I thought to myself, from my perspective as a natural philosopher with a strong background in Math and Physics, I cannot tolerate this. The matter is too serious, therefore let's try again.

Quantum superposition is mathematically described in Hilbert space, but rarely explained in terms of natural philosophy. Among the few who have done it in detail was Nobel Prize winner Paul Dirac in his book *The Principles of Quantum Mechanics,* (1930) which, to my surprise, is not included in the references of Li's article. Dirac's book should be read carefully. He speaks of principles of Quantum Mechanics. Principles refer to conditions which can be considered in terms of mathematics and in terms of natural philosophy.[3]

What are Dirac's principles? Dirac immediately starts in Chapter I with *The Principle of Superposition*. He understands this principle as fundamental to all quantum physics, which is why quantum theory must explain it. Now Li claims in his article that quantum superposition cannot exist at all. Well, one can claim a lot, but does it make sense for a new quantum theory beyond Dirac? I don't mean to argue that Dirac was a Nobel Prize winner and the first to have conceived the quantum field theory which contains Einstein's relativistic momentum, I only want to remark that he knew what he was doing when emphasizing the fundamental role of the principle of superposition. Let me quote Dirac in more detail:

"The general principle of superposition of quantum mechanics applies to the states of any one dynamical system. It requires us to assume that between these states there exist peculiar relationships such that whenever the system is definitely in one state we can consider it as being partly in each of two or more other states. The original state must be regarded as the result of a kind of superposition of the two or more new states, in a way that cannot be conceived on classical ideas. Any state may be considered as the result of a superposition of two or more other states, and indeed in an infinite number of ways. Conversely any two or more states may be superposed to give a new state...

The nature of the relationships which the superposition principle requires to exist between the states is of a kind **that cannot be explained in terms of familiar physical concepts**. One cannot in the classical sense picture a system being partly in each of two states and see the equivalence of this to the system being completely in some other state. There is an entirely new idea involved, to which one must get accustomed and in terms of which one must proceed to build up an exact mathematical theory, without having any detailed classical picture…

The non-classical nature of the superposition process is brought out clearly if we consider the superposition of two states, *A* and *B*, such that there exists an observation which, when made on the system in state *A*, is certain to lead to one particular result, *a* say, and when made on the system in state *B* is certain to lead to some different result, *b* say. What will be the result of the observation when made on the system in the superposed state? The answer is that the result will be sometimes *a* and sometimes *b*, according to a probability law depending on the relative weights of *A* and *B* in the superposition process. It will never be different from both *a* and *b*. *The intermediate character of the state formed by superposition thus expresses itself through the probability of a particular result for an observation being intermediate between the corresponding probabilities for the original states, not through the result itself being intermediate between the corresponding results for the original states*."…

…It is important to remember, however, that the *superposition that occurs in quantum mechanics is of an essential different nature from any occurring in the classical theory,* as is shown by the fact that quantum superposition principle demands indeterminacy in the results of observations in order to be capable of a sensible physical interpretation." (1930:13-14)[4]

What is this indeterminacy? Li claims that it is an indeterminacy with respect to location and time coordinates. He further claims that this is also classically valid and can be verified. Because of this unattainability of precise coordinates, the quantum superposition would become invalid. I do not want to go into the details of his mathematical discussions, which can be followed in his text, but I want to start at the core of the thesis: The unattainable coordinates. Physical theories consist of a formalism and an appropriate interpretation. The formalism is represented by a mathematical symbolism, the syntax, which allows the prediction of measured quantities. Objects of the real world can be assigned to these symbols. Thus, the theory receives an interpretation, its semantics. Classical physics is characterized by the fact that entities of reality can be assigned to its symbols without any problems and the assumption that reality does not depend on the observer. Quantum theory, however, contains formal objects whose relation to a reality independent of the observer leads to difficulties. For example, in quantum theory the location of a particle is not described by its spatial coordinates as a function of time, but by a wave function. Waves are infinite and non-local. There is the possibility of sharp maxima at more than one location. This wave function permits consequently only for each place the probability to find the particle there by measurement. But this wave function is not measurable for a single particle as a whole, because it is completely changed at the first measurement, a process which is also interpreted and called collapse of the wave function. This is called the

Copenhagen interpretation. Is there is a deeper underlying issue? Yes, there is, but due to a natural philosophical lack of comprehension it is hardly ever recognized recognized.

Usually, physicists refer to locations *x* or *r* and time *t*. Classically, this is valid throughout, but is it also valid in quantum terms? Classical mechanics is based on the field of real numbers

. Quantum mechanics is based on Hilbert space and this in turn on the field of complex numbers

. Classical physicists also use complex numbers, but only to make their work easier. Otherwise, they are irrelevant in the classical context. Quantum physicists, on the other hand, cannot use real numbers arbitrarily. There have been repeated attempts to conceptualize quantum mechanics with real numbers, each time failing because of quantum reality. The physicist Sunny Y. Auyang. discussed this in her book.[5] Recently Marc-Olivier Renou and others stated that *Quantum Physics needs complex numbers* and set up an inequality in the sense of Bell's inequality, with which one could decide empirically whether the quantum mechanics needs the complex numbers or not.[6]

The question arises, what does this have to do with superposition and the unattainable coordinates Li is talking about? The answer: In

there exist NO coordinates in the usual classical understanding of the locality *x* or *r* and the time *t*. For example, the usual corresponding rule based on the Hamiltonian:

Now the transformation:

Inserted in the wave-function

we get:

Real numbers for location and time in classical phase space are transformed into operators in complex Hilbert space. But where does the imaginarity *i* come from?

It is an appearance of 'hocus pocus' in the transition from classical mechanics to quantum mechanics, because for the imaginarity *i* the pious song applies: *From Heaven Above to Earth I Come* This 'hocus pocus' mapping of classical parameters into the imaginary quantum reality is also valid for the mapping of Einstein's special theory of relativity with the relativistic momentum into the Schrödinger equation by Paul Dirac. I do not want to doubt the immense success which this transmission achieved for the quantum field theory, but only to point out the natural-philosophical questionability of this success. However, this will certainly not prevent any practitioner to simply continue. The well-known 'hocus pocus' Wick rotation will certainly provide additional joy. One repeats with it apparently daily the Gaussian definition of the complex number. Just make a 90 degree counterclockwise rotation and the imaginarity *i* appears where it is needed. Really a hocus pocus miracle.

Certainly, location and time appear in the fundamental Schrödinger equation, but one should look closely at the (hocus pocus) correspondence principle and the resulting Schrödinger equation. After the transformation imaginarity *i* appears on the left outside of the Schrödinger equation. I.e., the whole Schrödinger equation is imaginary! My question: Has anybody ever seen a minus 5-meter bridge? Certainly never. But has anyone ever seen an imaginary *i*5-meter bridge? I think that not even Hollywood or the producers of Fake News or AI can imagine that. Imaginary realities are so absurd, it is believed, they cannot exist in reality, only in fiction. But it is a reality, for example of quantum superposition or entanglement. Renou, Auyang and others could demonstrate, without complex numbers

, i.e. without imaginarity *i*, there is no quantum mechanics!

Now the important question: What does this imply for locality or coordinates *x* or *r* and time *t*? My answer: Look at the correspondence principle. Coordinates *x* or *r* and time *t* simply disappear into the imaginary quantum domain and merge there in a coded way. They are no longer factual or 'real' as in their classical reality. Now they are only possible!

I want to draw the attention of sceptics of my point of view to the 'which-way experiment'. If one tries to find out in a double-slit experiment the locality or the coordinates of elementary particles behind the slits with the usual means of observation, the imaginary quantum reality breaks down and only the classical reality with classical localities and coordinates *x* or *r* as well as classical time *t* appears. There are no longer wave phenomena visible on the target, but, as usual in the classical version of the double slit-experiment, only two piles of dots behind the slits. This implies: Before the observations NO coordinates existed, only amplitudes.[7]

Li cites John S. Bell with his question: How does a quantum "and " get converted into a classical "or "? The 'which-way experiment' is an empirical answer to this question. But what does it mean? Solid-state physicist Helmut Föll of Kiel University, Germany, in his online hyperscript *Introduction to Materials Science* I,[8] has made remarkable natural philosophical observations on the imaginarity of the Schrödinger equation:

"A first stumbling block in trying to understand what Ψ represents is the fact that Ψ is usually a complex quantity - this did not exist in physics before! ...Thus, with an intrinsically or inherently complex wave function as a description of a physical reality, a complete break occurs both with classical physics and with the conventional view of nature, natural philosophy or metaphysics. Since we do not know any imaginary measurable quantities, it follows immediately that the wave function represents a higher level of abstraction than the usual measurable physical quantities. Thus, it cannot be measured directly, but must contain the desired information 'encoded'.

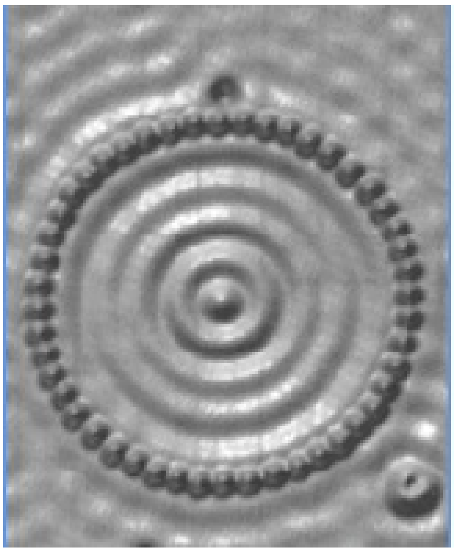
The Schrödinger equation is thus for the first time in the [history of] physics an equation for an abstract quantity, a quantity which can no longer be measured directly, and which thus remains inaccessible to the human senses. For only what is transformed by a measuring device (however complicated) into a quantity that humans can see, hear, feel, taste, or smell, we regard as real, as directly existent....

...It is one of the most fundamental equations of physics. With the Schrödinger equation, all of chemistry became a subfield of physics." (S.26-28)

We know that quantum mechanical observations yield only probabilities. Is there a mathematical reason for this? There is, but usually one does not look for it where it is. The complex number is defined since the times of Gauss in a Cartesian orthogonal coordinate system. What is almost never mentioned, the geometry of the complex number resembles the geometry of the theorem of Pythagoras. Among other things, the norm or amplitude is of interest. Exactly this norm is to be saved in the complex case only with the complex conjugate numbers. Pythagoras is, so to speak, extended into the negativity with this norm. But exactly this is the reality of the complex numbers and their imaginarity *i* in quantum reality. It contains the possibility of the superposition of plus and minus in the sense of the norm! If this complex norm is now in fact realized during an observation, thus factified, the superposed quantum imaginarity of plus and minus in the amplitudes collapses abruptly and only the known positive probability of the amplitude of an elementary particle remains because of this normalization, which Nobel laureate Roger Penrose has described beautifully in his book[9] in the context of 'Mysteries of the Complex Numbers'. Unfortunately he was not able to explain the mystery of the quantum norm in terms of natural philosophy.

So, coming back to Li's theory of the unattainability of precise coordinates, they simply do not exist in the context of quantum reality. They appear only in the formulas. They are classically NOT existent but exist only in a quantum imaginary domain in coded forms. They serve in this coded form for the calculation of the probabilities but have otherwise no 'factual' relevance. Only after the squaring of the norm they appear as probabilities and in such a way as classical facts in classical space and time, i.e. via coordinates. But what we get are probabilities, no coordinates! For example, it is known that quantum entanglement presupposes non-locality and a reality beyond the coordinates of space and time, aspects of quantum theory that made Einstein furious. The classical Einstein reality is called spatiotemporal, that is local and temporal. It is also factual. The quantum reality, on the other hand, is non-local and non-temporal. It is therefore also potential and consists of possibilities.

The scanning tunneling microscope can be used as an example. The fine needle moving over the sample has precisely detectable coordinates in classical 2-dim space and time. The following is a result that was obtained in 1993 by M. F. Crommie, C. P. Lutz, and D. M. Eigler of the IBM Research Division at Almaden Research Center in San Jose, California, USA.



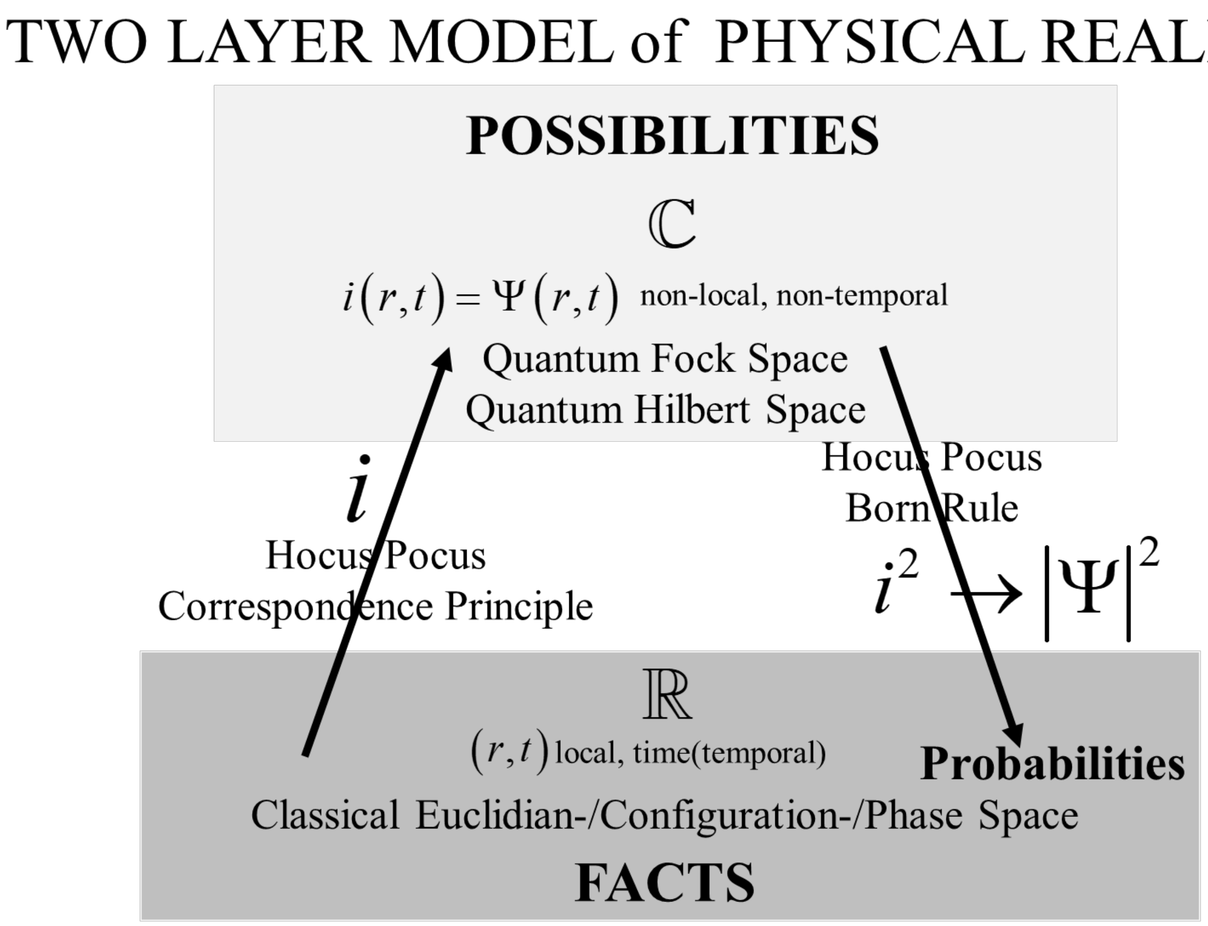
The ‘wave’ in the round corral formed by 48 iron atoms on the surface of copper is one electron. We ‘see’ directly with the scanning tunneling microscope the square of its wave function, or more precisely the square of the wave function just taken (the electron in the round potential well formed by the iron atoms has several possible states). What does this tell us?

The numerical value

indicates the probability of finding the particle classically at time *t* at location *x*. However, what is ‘observed’ or ‘seen’ there are NOT the coordinates of the non -classical imaginary quantum reality. This imaginary reality exists anywhere in wave form in the imaginary *n*-dimensional Hilbert space. What this quantum reality can be and do there has been described by the physicist Freeman Dyson in regard to Richard Feynman’s path integral:

“*Thirty-one years ago [1949], Dick Feynman told me about his ‘sum over histories’ version of quantum mechanics. ‘The electron does anything it likes,’ he said. ‘It just goes in any direction at any speed, forward or backward in time, however it likes, and then you add up the amplitudes and it gives you the wave-function.’ I said, ‘You’re crazy.’ But he wasn’t.*”

And neither is my response from a natural philosopher’s perspective to Li’s article on Quantum Superposition…[10], a perspective that is illustrated by my two layer model of physical reality:



[1] Qeios ID: N5HMJV https://doi.org/10.32388/N5HMJV

[2] https://www.informationphilosopher.com/solutions/scientists/einstein/dialectica.html. In German: *Quanten-Mechanik und Wirklichkeit*. In: Dialectica, 2, issue 3-4, pp.320-324 (1948)

[3] That reminds me of Isaac Newton's book *Philosophiae Naturalis Principia Mathematica* (1986) as a foundation of classical mechanics. *A Natural Philosophy based on mathematical principles*.

[4] The italic text passages are chosen by Dirac in his book. The bold from me. P.D.

[5] *How is Quantum Field Theory Possible*? 1995, p:74.

[6] Marc-Oliver Renou, David Trillo et al. *Quantum physics needs complex numbers*. 2021. arXiv:2101.10873v1. Kang-Da Wu, Tulja Varun Kondra, Swapan Rana et al. *Operational Resource Theory of Imaginarity* https://arxiv.org/pdf/2007.14847. (2021) They state: These results prove that complex numbers are an indispensable part of quantum mechanics. Renou, M.-O., Trillo, D., Weilenmann, M. et al. (2021) *Quantum theory based on real numbers can be experimentally falsified*. Nature 600, 625–629. Marc-Olivier et al. *Testing real quantum theory in an optical quantum network* https://arxiv.org/abs/2111.15128. (2021)

[7] This can also be read in the nice book of Richard P. Feynman & Albert R. Hibbs *Quantum Mechanics and Path Integral*. New York, 1965.

[8] In German. *Einführung in die Materialwissenschaft* I, https://www.tf.uni-kiel.de/matwis/amat/mw1_ge/index.html.

[9] Penrose, Roger: *The Emperor's New Mind*. Oxford. 1989, p.p.332-341.

[10] For a new natural philosophy of superposition with quantum entanglement, see Diederik Aerts and Massimiliano Sassoli de Bianchi Quantum entanglement partly demystified. 2023. https://arxiv.org/pdf/2306.04575.pdf