Filozofski vestnik | Volume XXXIV | Number 2 | 2013 | 49–60

Sašo Dolenc*

The Void of Quantum Reality

Quantum mechanics is probably the most successful scientific theory that has ever been created. It has profoundly changed our view of the world, extended the limits of our knowledge and is responsible for many technological breakthroughs that we use in our everyday life. But for all its success at the very essence, it remains a quandary that cannot be fully explained.

It is often said that no one understands quantum physics. At least that is a claim made by several distinguished physicists who have been awarded a Nobel Prize for their research on the quantum world. By this lack of understanding they normally refer to the unusual traits of quantum particles that are impossible to explain through any analogy with everyday life. Quantum particles are crazy, as Richard Feynman once remarked, but all to the same extent: all of them can at the same time travel along different paths, appear in different places, and possess incompatible characteristics; but that does not seem to disturb them at all.[1]

For a long time, physicists ignored the problem of "quantum weirdness" as something that cannot be approached scientifically. Especially in decades after the Second World War, philosophical questions concerning scientific theories became almost forbidden topics for scientists who wanted to pursue their academic careers.

> Thirty years ago, readers who were interested in the unsettled debates over the interpretation of quantum theory had to hunt in some out-of-the-way places. In 1979, some of the most extensive coverage appeared in an unpublished memorandum from the Central Intelligence Agency and a feature article in *Oui magazine*. The latter—no publication of the French embassy—was *Playboy's* answer to *Penthouse*. Both items focused on work by physicists at the center of this story.

[1] Richard P Feynman, *QED: The Strange Theory of Light and Matter.* (Penguin, 1990), p. 9.

* University of Ljubljana, Slovenia

> The porn magazine's discussion was by far the better researched and more accurate of the two.[2]

Regarding the problems of quantum mechanics the pragmatic approach "shut up and calculate" became the official ideology in most scientific departments at universities around the world.

> Most students are taught about quantum theory as though the conceptual and philosophical problems do not exist or are irrelevant to their understanding. Either by design or default they are fed the orthodox "Copenhagen" interpretation of quantum theory, originally developed by Niels Bohr, Werner Heisenberg, Wolfgang Pauli and their colleagues in the 1920s and 1930s. When faced whit theory's inherent non-understability under this interpretation, student are likely to blame themselves for failing to come to terms whit what is one of the most important theoretical foundations of modern physical science. This is a great pity, because this non-understability can, in fact, be traced to anti-realism of the Copenhagen interpretation. The theory is, quite simply, not *meant* to be understood.[3]

The foundational principle for quantum mechanics

Anton Zeilinger, one of today's most important quantum physicists, who spent a number of years working mostly on experimental quantum physics and studying quantum teleportation, quantum cryptography, quantum computers and interference experiments with multi-atom molecules, has dedicated the last couple of years also to writing about the interpretations of quantum physics, or in other words, the problems associated with this simple question: what does all this quantum nonsense even mean?

In 1996, he began critically examining the ways quantum mechanics had been written about, concentrating on how the pioneers of modern physics had discussed their work in their private correspondence. He gathered his findings in a concise article, which concluded that quantum physics needs a clearly formulated basic principle to sum up its essence.

---

2 David Kaiser, *How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival* (W. W. Norton & Company, 2012), p. xii.

3 J. E Baggott, *Beyond Measure: Modern Physics, Philosophy, and the Meaning of Quantum Theory* (Oxford; New York: Oxford University Press, 2004), p. xv.

The basic principle of the theory of relativity is, in very simplified terms, that nothing can travel faster than light, that the laws of nature are the same for any observer and that we cannot separate gravity from acceleration. According to Zeilinger, quantum physics needs something just as simple, clear and universal. In 1999, Zeilinger published an article entitled *A Foundational Principle for Quantum Mechanics* in which he formulated the basic principle of quantum physics, using the principles of the theory of relativity as a model. His proposal for the basic principle of quantum physics is: The elementary system carries one bit of information.[4]

Naturally, these questions instantly arise: what is information and what is the elementary system? As he says himself: information is nothing else than the answer to the questions asked. The bit is the smallest piece of information that can still mean something. It is the smallest, indivisible unit of information. It simply states whether a statement is true or false. One could also say that it is the answer to a question which can only have two possible answers: yes or no. One bit of information can be represented simply as the presence or absence of a signal: a light turned on or off, the magnetization on a tiny piece of a hard disc, an indentation on the surface of a CD.

When Zeilinger was thinking about information in the quantum universe, he also asked himself the important question of the relation between the physical size of a system and the quantity of information that the system can carry. A system which is two times smaller than another will probably carry two times less information. If we continue to divide a certain system by two, we are bound to eventually reach a limit where our system can only carry a single piece of information, one bit. That is how Zeilinger defined the elementary system as the carrier of a single bit of information.

But at the level of basic carriers of information that cannot be further divided, problems emerge:

> What happens now when the light source is attenuated until finally only a single quantum of light – a photon – is transmitted? What should we expect when the

4 Anton Zeilinger, “A Foundational Principle for Quantum Mechanics,” *Foundations of Physics* 29, no. 4 (1999): p. 631–643.

> switching process of a transistor is already triggered with a single electron? In quantum information science, quantum objects are used as carriers of information. […] While there are only two possibilities "0" and "1" allowed for the classical bit, the quantum system can be in any state that results from a superposition of the two basic settings. […] The value of the bit itself is therefore quantum-mechanically uncertain. Any observation will show one of the two values with the given probability as a result. Does this uncertainty not actually go together with a loss of information?[5]

As more and more physicists became interested in information problems in the quantum universe, the term quantum bit or qubit started to replace Zeilinger's elementary information carrier. The qubit is thus the basic carrier of quantum information. It is in a way an atomic element in quantum terms. Using this new term we could reformulate Zeilinger's basic principle into something like: one qubit can carry one bit of information.

However, the problem with qubits is that it is not possible to double them. A qubit cannot be cloned without destroying the original we wish to double. A qubit can also never be read with complete accuracy. If we discovered a process to multiply it, we could use the many identical copies to examine it thoroughly and precisely define it. As it is impossible to double it, one measurement of a qubit only reveals a single bit of information, and the essence of the quantum universe always remains invisible to a certain extent.

According to Zeilinger, all problems stem from the very fact that information is quantified. We simply cannot acquire less than one bit of information about the world. It is the absolute minimum, which at the same time means that the resolution of the world itself is limited to one bit of information. One qubit only gives us one bit of information. One qubit can only answer a single yes or no question. If we continue to question it via further experiments, its answers will not make any sense at all or will be, as Zeilinger puts it, objectively random. But at the same time we know that qubit has a structure that is more complex than that of a bit.

5 Harold Weinfurter, "Quantum Information," in *Entangled World: The Fascination of Quantum Information and Computation*, ed. Jürgen Audretsch (Wiley-VCH, 2006), p. 146.

The fundamental problem of quantum physics lies in the difference between the qubit and the bit. The qubit contains more regularities than we can see. Zeilinger says:

> So, what is the message of the quantum? I suggest we look at the situation from a new angle. We have learned in the history of physics that it is important not to make distinctions that have no basis — such as the pre-newtonian distinction between the laws on Earth and those that govern the motion of heavenly bodies. I suggest that in a similar way, the distinction between reality and our knowledge of reality, between reality and information, cannot be made. There is no way to refer to reality without using the information we have about it.[6]

Just as the special theory of relativity is based on the impossibility of differentiating between inert observers (the principle of relativity) and the general theory of relativity on the impossibility of differentiating between gravity and acceleration (the equivalence principle), quantum theory is supposed to be founded on the impossibility to differentiate between the real world and information about it: the laws of nature should not separate reality from information. It is impossible to differentiate between the real world and information we gather about that world.

Zeilinger's principle formulates something similar to what the Danish physicist and the author of famous Copenhagen interpretation of quantum physics Niels Bohr probably wanted to say when he wrote:

> There is no quantum world. There is only an abstract physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature...[7]

Bohr was convinced that humans, because of specific nature of cognition, perception and limitations of our language, could never picture the inner mechanisms of the atom. We cannot approach quantum reality in any other way than through information or through events in classical reality. But at the same time

6 Anton Zeilinger, "The Message of the Quantum," *Nature* 438, no. 7069 (December 8, 2005): 743, doi:10.1038/438743a.

7 Jonathan Allday, *Quantum Reality: Theory and Philosophy* (Boca Raton, FL: CRC Press, 2009), p. 281.

we know that qubit is "something more" than a bit we can measure. The nature of this "surplus" at the very essence of qubit precisely is the main problem with the interpretation of quantum physics.

Quantum world doesn't exist?

New Scientist recently reported on a new version of the famous double slit quantum experiment. Scientists used a quantum particle in a state of superposition to open or close one of the possible ways a particle can travel through the measuring apparatus. However, the details of this experiment are not important for us at the moment, as we are only interested in a "philosophical" discussion on the results of the experiment that the author offers at the end of his presentation. He quotes one of the scientists who carried out the experiment:

> It's a notion that takes us straight back into Plato's cave, says Ionicioiu. In the ancient Greek philosopher's allegory, prisoners shackled in a cave see only shadows of objects cast onto a cave wall, never the object itself. A cylinder, for example, might be seen as a rectangle or a circle, or anything in between. Something similar is happening with the basic building blocks of reality. "Sometimes the photon looks like a wave, sometimes like a particle, or like anything in between," says Ionicioiu. In reality, though, it is none of these things. What it is, though, we do not have the words or the concepts to express.[8]

In this quote, quantum reality is interpreted as a kind of independently existing and fully constituted world that we just cannot approach directly. Quantum reality is presented as something that has full independent existence, but is inaccessible to us in any direct way. We can only see the shadows that quantum objects cast on the walls of the cave and this is the reason why we sometimes see the same quantum object as a wave and sometimes as a particle.

This interpretation of quantum physics in which quantum reality is presented as something existing independently but at the same time not fully accessible to us, is a typical example of how we cannot understand the philosophical implications of quantum mechanics.

---

8 Anil Ananthaswamy, "Quantum Shadows: The Mystery of Matter Deepens," *New Scientist*, January 5, 2013.

If there is a metaphysical conclusion that we can deduce from quantum physics, it is as follows: qubit as the essence of quantum strangeness cannot be interpreted as something substantial, or as the stuff the world is made of. Quantum description is not a mirror picture of "world down there", as it exists for itself. But at the same time quantum theory is also not just an abstract theory that says nothing about what the world is really like.

What is so subversive in quantum mechanics is the fact that experiments prove that there are events in the world that we just cannot interpret consistently using our common everyday notion of reality. There is something in the world that we can predict using mathematical equations, but at the same time this something does not have proper representation in our classical everyday understanding of reality.

> All the various measurement that we make on atoms and particles in the end come down to numbers read from dials (or similar) on measuring apparatus. [...] So we are caught in dilemma. The experiments we carry out should not only be capable of being described in, essentially, everyday language, but they *must* also be so to make science possible. Yet, when we try to gather the results of our experiments together to make a description of the atomic world, we find that the same everyday language and ideas start to fail. Photons seem to act as particles in some circumstances and as waves in others. We can find appropriate mathematics to describe the situation, but that doesn't help us visualize or speak about photons.[9]

We cannot interpret what goes on at the level of atomic particles without using concepts of everyday reality. Experiments are made using measuring equipment that displays results in a classical way. Everything we know about quantum reality we know through measurements that are made using concepts of classical reality.

We cannot approach quantum reality in any other way than through information or through events in classical reality. But at the same time we know that qubit is "something more" than a bit that we can measure. We can prove that there is something at the level of quantum objects that does not add up, and that the picture of quantum reality is in this regard incomplete.

9 Allday, *Quantum Reality*, p. 291.

The point is that qubit has a structure that we know carries more information than just one bit we can get from one qubit. But once we extract one bit of information out of a qubit, it can give us no further information. Anything else we get after that is objectively random or completely without any meaning.

Status of irrational numbers in Pythagorean universe

We will try to understand the philosophical implications of quantum physics by using a famous anecdote from ancient Greek mathematics. It is well-known that Pythagoreans believed in a harmonious universe in which numbers were the basic elements of reality. By numbers they meant positive integers if we use today's mathematical language.

As the story goes, one day, a man called Hippasus discovered that there is something wrong with the diagonal of a square. He was able to prove that the diagonal and the side of a square cannot be expressed by any two integers. He constructed a proof that there is no common measure between the diagonal and a side of a square. Or expressed in today's words: he proved that the square root of 2 is an irrational number, meaning that it cannot be expressed by fraction of two integers.

It became obvious that one of the most elegant of all geometric shapes has in its very structure something that cannot be expressed in a relation of two integers and cannot be a part of the harmonious universe or reality as defined by Pythagoreans. Two well defined geometrical magnitudes did not have a proper representation in the harmonious universe.

The ancient story goes that Pythagoreans were so terrified by this discovery that they took Hippasus out to sea and threw him overboard. Later, even other Greek mathematicians that were not members of the Pythagorean sect were also so horrified by this discovery that they turned their backs on numbers and started doing mathematics using geometry instead. One of the sources of this legend is *The Commentary of Pappus on Book x of Euclid's Elements*:

> Indeed the sect (or school) of Pythagoras was so affected by its reverence for these things that a saying became current in it, namely, that he who first disclosed the knowledge of surds or irrationals and spread it abroad among the common herd,

> perished by drowning: which is most probably a parable by which they sought to express their conviction that firstly, it is better to conceal (or veil) every surd, or irrational, or inconceivable in the universe, and, secondly, that the soul which by error or heedlessness discovers or reveals anything of this nature which is in it or in this world, wanders [thereafter] hither and thither on the sea of non- identity (i. e. lacking all similarity of quality or accident), immersed in the stream of the coming-to-be and the passing- away, where there is no standard of measurement.[10]

For our purpose it is of no importance if the story is genuine. We just want to use this famous ancient mathematical discovery as a model to understand some of the problems instigated by quantum physics.

The essence of the Pythagorean problem regarding irrational numbers was in the following paradox: this kind of proportions should not exist in an ideal harmonious world, but at the same time it was shown that they should exist if we take the fundamental principles of this world seriously.

If rational numeric proportions were fundamental building blocks of reality, irrational proportions were something that could not be part of this reality. But there was proof that from within this harmonious vision of the world irrational proportions of this kind do exist.

It is important to be aware of the fact that irrational proportions are not something that is fundamental and exists independently of the harmonious view of the world. Their existence depends on the harmonious conception of the world. We have only obtained proof that some proportions don't have a representation in a system that by definition should cover everything. There are no irrational numbers existing on their own, at least not in the Pythagorean universe. They exist simply as an obstacle in the harmonious conception of the world, which prevents the Pythagorean model of the world from ever being complete.

The Pythagorean harmonious world cannot in this sense ever fully realize itself. It is always already not complete. We can always prove that there is something

10 Pappus of Alexandria, *The Commentary of Pappus on Book x of Euclid's Elements*, trans. William Thomson (Harvard University Press, 1930).

missing, but the element that is missing is nothing else than an obstacle, which prevents the world to be on the level on which it is supposed to be from within.

The structure of the void of quantum reality

Our thesis is that there are important similarities between horrors of irrational proportions within the Pythagorean vision of reality and problems instigated by the interpretation of quantum physics in our everyday vision of reality. In the same way as the Pythagorean vision of the world presupposes reality as harmony of numbers or rational proportions, our notion of reality presupposes certain way of understanding what the world is and how to comprehend it. Quantum physics has the same effect on our vision of reality as irrational proportions had on the Pythagorean reality.

The main problem with Zeilinger's fundamental principle of quantum physics is that it starts from naive understanding of division between the reality and information. His implicit understanding of reality is that it exists independently of the observer. He positions a gap between the knowing subject and the object--to-be-known, and then deals with the problem of how to bridge this gap. But one of the most important implications of quantum theory is the conclusion that we must, as far as quantum physics is concerned, abandon this common sense division between the fully realized objective reality as the substance of the world and subjective information we can have about this reality.

One of the ways we can understand the notion of "reality out there" in quantum physics is to interpret it as objective randomness or complete absence (void) of information that is one of the fundamental consequences of quantum theory. As Zeilinger formulated, in quantum physics, the problem is not that our capacities for understanding the diversity of the quantum universe are too limited, but the fact that inevitable randomness is inherent to the very structure of the world.

> The discovery that individual events are irreducibly random is probably one of the most significant findings of the twentieth century. Before this, one could find comfort in the assumption that random events only seem random because of our ignorance. [...] But for the individual event in quantum physics, not only do we

> not know the cause, there is no cause. [...] There is nothing in the Universe that determines the way an individual event will happen.[11]

One qubit only gives us one bit of information. One qubit can only answer a single yes or no question. If we continue to question it via further experiments, its answers will not make any sense at all or will be, as Zeilinger puts it, objectively random.

> But the individual measurement result remains objectively random because of the finiteness of information. I suggest that this randomness of the individual event is the strongest indication we have of a reality "out there" existing independently of us. Maybe Einstein would have liked this idea after all.[12]

Objective randomness is defined as complete absence of any kind of information. In this sense "reality out there" that Zeilinger talks about is pure void of meaning or information.

But this kind of understanding of the "quantum reality" as a version of Kantian thing-in-itself is over-simplification. Qubits are not "atoms of being" or basic units of the fundamental substance of the material world, even if they are in a way beyond the grasp of our experience. There is no other "more real" quantum reality outside what is given to us through experiments and observations. What is important is not to interpret qubits as something that can exist independently of anything else.

The status of qubits is similar to that of irrationals in the Pythagorean conception of reality. They are real, but not real as independent of a system within which they originated. In the same way as irrational proportions are not primary, basic or fundamental units in the Pythagorean world, qubits as atoms of quantum reality are also not something that exists independently and "casts shadows" on our perceptive world.

The essence of quantum reality, or what is more in qubit that cannot be expressed in a bit of information, is from one perspective pure void, objective randomness

11 Zeilinger, "The Message of the Quantum."
12 *Ibid.*

and nothing we can ever measure or experience, but from the other perspective it has a fully specified mathematical structure that we can present using the equations of quantum physics. The Pythagorean analogy can help us understand this unusual paradox of "the structure of the void of quantum reality".

References

Allday, Jonathan. *Quantum Reality: Theory and Philosophy*. Boca Raton, FL: CRC Press, 2009.

Ananthaswamy, Anil. "Quantum Shadows: The Mystery of Matter Deepens." *New Scientist*, January 5, 2013.

Baggott, J. E. *Beyond Measure: Modern Physics, Philosophy, and the Meaning of Quantum Theory*. Oxford; New York: Oxford University Press, 2004.

Feynman, Richard P. *QED: The Strange Theory of Light and Matter.* Penguin, 1990.

Kaiser, David. *How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival*. W. W. Norton & Company, 2012.

Pappus of Alexandria. *The Commentary of Pappus on Book x of Euclid's Elements*. Translated by William Thomson. Harvard University Press, 1930.

Weinfurter, Harold. "Quantum Information." In *Entangled World: The Fascination of Quantum Information and Computation*, edited by Jürgen Audretsch. Wiley-VCH, 2006.

Zeilinger, Anton. "A Foundational Principle for Quantum Mechanics." *Foundations of Physics* 29, no. 4 (1999): 631–643.

---, "The Message of the Quantum." *Nature* 438, no. 7069 (December 8, 2005): 743. doi:10.1038/438743a.