Module 1, Lesson 2 - final transcript and srt.

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SPEAKERS

Marco Colnaghi, PhD

M Marco Colnaghi, PhD 00:03

Welcome back to "A Beginner's Guide to Quantum Mechanics." In the last lesson, I explained how, although the equations of quantum theory are extremely accurate, it is unclear what they really tell us about the way things exist, about the ontological status of quantum phenomena. So today, I'm going to give you some more details about a few of the most important interpretations of quantum mechanics that have been proposed during the years and their philosophical implications.

M Marco Colnaghi, PhD 00:42

I will start by explaining the difference between realist and non-realist interpretations, which is a useful way of comparing different interpretations and the relative weight they put on the role of the observer (of the agent who performs a measurement, or the consciousness of that agent). And then I will talk about another conceptual tool called the "Heisenberg cut", which is another useful tool to discuss the differences between various interpretations of quantum mechanics. Then we'll discuss some of the most important and famous interpretations of quantum mechanics starting from the "neo-Copenhagen" and the "classical Copenhagen" interpretations. They were both named after the hometown of Niels Bohr, who was one of the foremost theoretical physicists who contributed to the development of quantum theory. Then I will move on to "Bohmian Mechanics" named after David Boehm, to the "Many Worlds" interpretation, the "Van Neumann-Wigner" interpretation, which places an important role on the consciousness of the observer. And then I will move on to Carlo Rovelli's "relational interpretation" and "Qbism", which will be discussed at length, especially in the following four modules.

M Marco Colnaghi, PhD 02:15

So, let us start. What is a realist interpretation of quantum mechanics? Well, a realist would say that the physical world exists out there, and it's independent from the presence or the activity of subjective observers. In other words, the world is mind independent, it's independent from minds observing it. So the properties of the physical universe are established and well defined, whether or not we make a measurement of these physical properties. And measurement only reveals something which is already existing, certain physical property with a well defined value, it makes it manifest. But there was something already there, which is not much impacted by the act of measuring, the act of observing the world. And Einstein was a proponent of realists' interpretations, and argued against non-realist interpretations. He said that: "God doesn't play dice with the universe." So, he was arguing for a deterministic description of the laws of nature, as opposite to the probabilistic description that we've touched upon in the last lesson.

M Marco Colnaghi, PhD 03:47

Non-realist interpretations on the other hand, are based on the idea that the subjective experiences of conscious observers shape the properties of the physical world. In other words, the world is dependent on the minds observing it, consciousness has a causal role in shaping the properties of the physical world. Or, in a slightly less extreme interpretation, we could say that measurement has an impact on the physical world. So the process of observing the world changes it: has a role in shaping it. For example, by causing the collapse of the wavefunction of a quantum, which describes the state of a quantum system. This position was somehow represented by Niels Bohr, who was a proponent of a probabilistic description rather than a deterministic one. And his famous answer to Einstein's statement was something along the lines of: "Einstein, stop telling God what to do!" And of course, this wasn't meant in a religious way, but more like: don't try to bend the laws of nature to your ideas about how nature should behave, there is experimental evidence that the world behaves in this probabilistic way. Although, as you will see, certain interpretations will lean more to the realist side, others more towards the non-realist interpretation.

M Marco Colnaghi, PhD 05:29

Another useful tool to classify and define different theories different interpretations of quantum theory is known as the "Heisenberg Cut". And, it is a conceptual distinction between the observed system, which is an entity described by the laws of quantum physics, whose properties are being measured and described, and the observing system, which is the agent that performs the measurement along with all the measuring devices that are used. And this is described by the laws of classical physics. So, how can we discriminate between the two, when ultimately, all the matter in the universe on a fundamental, microscopic level, behaves according to the laws of quantum physics?

M Marco Colnaghi, PhD 06:24

Well, the "Heisenberg Cut" is a conceptual split of the world in two parts, the observed quantum world, described by the laws of quantum mechanics, and the observer and all the experimental tools they use, which is considered to be the classical world. And separating these two domains is the "Heisenberg Cut". And, as you will see, the position of the cut changes depending on which interpretation of quantum mechanics we study and therefore, provides a good way of classifying them and understanding them better. And I want to acknowledge these paper by Nurgalieva and Renner, "Testing Quantum Theory with Thought Experiments", on which I have drawn to put this material together.

M Marco Colnaghi, PhD 07:24

So, the "Copenhagen Interpretation" was mainly developed by Niels Bohr and Werner Heisenberg. And it was named after Niels Bohr's hometown: Copenhagen. In the classical Copenhagen interpretation, the cut is objective. That is, it's the same for all observers, and they must all be placed on the classical side of the cut. So, if there are several observers performing an experiment, they will all be considered to be in the classical domain, and the observed system will be in the quantum domain. If any observer in the classical domain performs a measurement on the quantum system, it causes its wavefunction to collapse for all observers. This interpretation was slightly revised, partially because it doesn't really explain how, for example, Wigner's paradox that we discussed in the previous lesson, it's hard to say, what happens when two different observers have access to a different amount of information about a quantum system, then they can come up with two contradictory statements about the system. So, the new Copenhagen interpretation, the modern Copenhagen interpretation, solves this problem by stating that the Heisenberg Cut is in fact subjective: each and every observer has a different subjective positioning of the cut. And the only rule is that they must place the cut between themselves and the observed system. They cannot be on the quantum side of the cut. So any agent is necessarily in the classical world, at least for themselves, although they could include other agents on the quantum side of the Heisenberg cut.

M Marco Colnaghi, PhD 09:35

So for example, if you look at this representation, where I've represented different observers with different colours, and I've used a very inappropriate depiction of an atom as a representation for a quantum system. Remember, well-defined trajectories exists only in the language of classical physics. So please forgive me for this inaccurate depiction of a quantum system. So the first observer considers the quantum system to be on the quantum side of the Heisenberg cut, and themselves and any other observer on the classical side of the cut. However, for observer number two, and this could depict very well the situation of the Wigner's paradox described in the previous lesson. They themselves are on the classical side of the cut, but observer one, as well as the measured system, are both in the quantum domain, so, observer two will use a quantum formalism to describe the behaviour of both observer one and the quantum system.

M Marco Colnaghi, PhD 10:58

It follows that if the first observer makes a measurement on a quantum system, they will cause the quantum wavefunction to collapse from their point of view, but not from the point of view of observer two, who is not observing a single quantum system, but he's observing a coupling between observer one and the quantum system. So, if you wish, this expanded system from the perspective of observer two, has a different wave function, which does not collapse if observer one makes a measurement. It only collapses when observer two, say, opens the door to the lab and has access to the information about both observer one and the quantum system.

Marco Colnaghi, PhD 11:51

Another prominent interpretation was brought forth by David Boehm. And it's therefore known as "Bohmian Mechanics" and unlike the Copenhagen Interpretation and other interpretations, it is a deterministic theory. This is based on a concept known as "hidden variables", which are properties of the physical world, which cannot be directly measured, but which influence the behaviour of quantum systems and give rise to what appears to be a probabilistic behaviour. But, in fact, is deterministic and it's caused by these hidden variables, which direct the behaviour of quantum systems. And one example, and this is one of the main features of Bohmian Mechanics, is the presence of what is known as "quantum potential", which guides quantum particles and can account for their sometimes wave-like behaviour that we also discussed in the previous lesson, such as what is revealed by the double slit experiment.

Marco Colnaghi, PhD 13:06

So, another important result of quantum theory is known as "Bell's Theorem". And I'm not going to discuss it in detail, because it's a slightly more advanced topic, but what you need to know about it, is that it states that any theory based on hidden variables must be a "non-local theory" of reality, hidden variables must be non-local. So it means that any particle, any entity in the whole universe influences everything else. So Bohmian Mechanics is a theory of the whole universe. There is no such thing as an isolated quantum system. And therefore, the whole universe is described as a single quantum system and it's all below the cut. It's all on the quantum side of the cut: there is no classical side. And this includes any agent performing a measurement - it includes any observer. So, an observer using Bohmian Mechanics must take into account the wave function of the whole universe, which is seen as an undivided, interconnected whole, and it includes the observers themselves.

Marco Colnaghi, PhD 14:34

So, similarly to Boehm's interpretation, in the "Many-Worlds" interpretration, the whole universe is described as a single quantum system. However, the main feature of this interpretation is that the process of observation causes a branching of the universe into multiple universes. So, if the system exists in a superposition of N different states, a measurement will cause the universe to branch, to split into N different universes. In each of them, one of the possible N states is realised. So, for example, if an observer performs a measurement on a system, which has only two states, A and B, this will cause the universe to split into two different branches. One where the observer perceives and measures A, and one where the observer perceives B. So, what is experienced by individual observers as the collapse of the wavefunction is, in fact, the process of the universe branching into many different universes. So, like Bohmian Mechanics, this is also a deterministic theory of reality. Rather than saying that, like Copenhagen Interpretation, the quantum function collapses into a single state, it states that it collapses into all possible states. But that each of these different possibilities is realised as a wholly new universe.

Marco Colnaghi, PhD 16:34

Another relevant interpretation, because of its philosophical implications, is known as the "Von

Another relevant interpretation, because of its philosophical implications, is known as the "Von Neumann-Wigner" interpretation. So, as we discussed in the previous lesson, measurement is said to cause the collapse of the wavefunction, which describes the state of a quantum system. But what is it exactly that causes the wavefunction to collapse? There is nothing in the Schrodinger's equation or in other quantum mechanics equations, that actually explains the reason why the system collapses into a single state. So, there is a causality chain, which goes from the subjective experience of the observer, to their brains and nervous systems and sense organs perceiving the information, to the interaction between the observer and measuring instruments (which again, I have inappropriately represented here, with a telescope). And eventually, to the last link of the chain which is the interaction between the measuring instruments and the observed system, which is described by the laws of quantum physics.

M Marco Colnaghi, PhD 17:51

So, in principle, any element in this causal chain could be the ultimate cause of the collapse of the wave function. So, from the point of view of this interpretation, the measuring instruments as well as the brain and the sense organs of the agents who perform the measurements, are themselves made by atoms and subatomic particles, which of course, obey to the laws of quantum physics. In principle, there is nothing which distinguished them from the observed system, they too must be described by the laws of quantum physics. So, the only element outside of the laws of quantum physics is considered to be the consciousness of the observer, their subjective, perceptual experiences of the world. And so, according to this interpretation, given that everything else is based to the laws of quantum physics, it must be consciousness itself, because of being qualitatively different from the rest of the universe, that causes the collapse of the wavefunction, both in the brains of the observers and in the observed systems. So, the whole universe is described as a single system obeying the laws of quantum physics, and consciousness is considered to be non physical and to be the real entity that performs measurements causing the wavefunction to collapse.

M Marco Colnaghi, PhD 19:38

So, we come to the "Relational Interpretation" which was developed by Carlo Rovelli, who also features on this course. And, in a way, this interpretation really turns the "Von Neumann-Wigner" interpretation on its head because it states that consciousness does not have any privileged role in causing the collapse of the wavefunction. According to this interpretation, the observer does not need to be a conscious agent. And by stating this, it teases apart two difficult problems, which are the "hard problem of consciousness" and the status of quantum phenomena between measurements. So, according to this interpretation, the properties of a physical system are not to be considered objective, there is no such a thing as an absolute property. And they are not the same for all observers, any physical system can be an observer, can be considered as an observer. And different properties emerge depending on the relation between the first system taken as a reference point. And the second system which is considered to be the observed system.

M Marco Colnaghi, PhD 21:04

So, in fact any statement about the state of a system, is not an absolute statement, but rather, it's a statement about the relation between the system taken as a reference and the observed system. And this idea is analogous to the principle of Einstein's "Theory of General Relativity". So, two different observers can make two equally valid, but different and even contradictory statements, about the same quantum system. And, when I use the word "observer" here, it means any physical system: it does not need to be a conscious agent. So, to sum up, according to the Rovelli's interpretation, there are no absolute, but only relative properties. And you'll hear from him how this interpretation can connect with some very ancient ideas of Buddhist philosophers, such as Nagarjuna, in his conversation with Geshe Tenzin Namdak, in modules four and five (of this course).

M Marco Colnaghi, PhD 22:19

Another interpretation which is discussed at length during the course, because of its connections with Buddhist epistemology, is known as Qbism, which stands for Quantum Bayesianism - that's quite a mouthful, I know. It was named after a concept in probability theory known as Bayesian probability. According to this interpretation, quantum theory is not a theory about ontology - it's not a theory about the way things are. But it's a normative theory: that is, a set of tools that an agent can use to evaluate their beliefs and expectations about the world, and to adjust their course of action to make decisions based on those beliefs, expectations and predictions.

M Marco Colnaghi, PhD 23:11

So it's not a theory of the physical world in itself. Rather, it is a tool to calculate probabilities of encountering certain outcomes based on previous knowledge of the world. So in this sense, all observers put themselves on the classical side of their subjective Heisenberg Cut, and the rest of the universe, including all other observers, on the quantum side of it. So from the perspective of observer one, they themselves are in the classical domain, the rest of the universe is in the quantum domain, including any other observer. Same for observer two and any other conscious agents in the universe.

M Marco Colnaghi, PhD 24:03

So, to sum up today, we've discussed the difference between realist and non-realist interpretations. And we've talked about Bohmian Mechanics and Relational Quantum Mechanics, which are really theories, as they do not require conscious observers: they say that the properties of the physical universe exist regardless of the consciousness of agents who are performing measurements.

M Marco Colnaghi, PhD 24:35

The conventional and new Copenhagen interpretations combine some realist with some non-realist elements, as they agree that there is an objective world out there. However, they state that the properties of the physical world change when measurement is performed, as the observer and the process of measuring the world causes the collapse of the wave function. So, the process of observation shapes the properties of the physical world.

M Marco Colnaghi, PhD 25:11

On the other end of the spectrum, we have the "Von Neumann-Wigner" interpretation, which argues that consciousness has a causal role in causing the collapse of a wave function. And ultimately, without consciousness, there would be no collapse of the wave function, the world would be in an undetermined state. And Qbism can be considered a pragmatist theory, there is some debate in the literature as to whether it should be classified as a realist or a non-realist theory. But it considers that there is a world out there from the perspective of a subject, who, however, has limited information about it. So, we could say that it's a subjective theory, but it does have a realist element: in the sense that the subject can use the theory to navigate the world, although they have access to only a limited amount of information about the world itself.

M Marco Colnaghi, PhD 26:25

As a conclusion, we've discussed wildly different interpretations of quantum theory. And there is no interpretation that can be said to be truer or more accurate than others. And there are some more which we haven't touched upon, not least the so called "shut up and calculate" interpretation, which states that people shouldn't worry too much about the ontological implications of quantum physics, but just use it to calculate the outcome of measurements and experiments and to develop new technology: we don't really need to know what the ultimate nature of reality is, as long as we can make accurate calculations. So it is hard to say, what is the best interpretation of quantum mechanics? Certainly, I won't make any claims about it. And we'll let you make up your own mind as you go through the course. And I hope that the next modules will help you to decide what interpretation of quantum theory seems most plausible for you.

M Marco Colnaghi, PhD 27:39

You will also see that some of these interpretations have a greater affinity with some tenets of Buddhist philosophy. In particular, the Mind-Only school presents a great degree of affinity with the "Von Neumann-Wigner" interpretation, as it places an emphasis on the role of consciousness. You will hear Michel Bitbol and John Dunne in modules two and three, respectively, talk about Dharmakirti's epistemology, which is also very close to some of the tenets of Qbism. And finally in modules four and five, you will hear more about the connections between Nagarjuna's Middle Way school and Relational Quantum Mechanics by Carlo Rovelli himself in a conversation with Geshe Tenzin Namdak.

M Marco Colnaghi, PhD 28:40

As a final remark, I'd like to thank wholeheartedly Dr. John Realpe, who helped to put together this material, as well as all the staff and volunteers of Jamyang London Buddhist Centre, and Science & Wisdom LIVE, who've helped to create and shape this course. I hope you have found this introduction to quantum mechanics useful and clear, and that you will enjoy the rest of the course. Thank you for your time and attention and best of luck with your studies.