QUÂNTICO

Episode 04 - IS THIS REAL OR IS IT JUST GOING ON IN MY HEAD?

"Italic": Excerpt pseudoscience speech

[in brackets]: sound effect

OPENING: DISCOVERY OR INVENTION? ************************************

[intro - bass]

Gláucia - Lu, do you remember the story of Archimedes?

Lu - Archimedes is from Ancient Greece, right? Isn't that the one who runs around naked shouting eureka, eureka?

Gláucia - So, there is this story that a king handed over a certain amount of gold, let's say, two kilos of gold, to a goldsmith to make a crown for him. Then after a while the goldsmith delivered a beautiful golden crown that weighed two kilos. But the king became suspicious that the goldsmith might have mixed the gold with another, less valuable metal. But it was just a suspicion and the crown was beautiful, and he didn't want to take the crown apart to check it... So he decided to ask Archimedes for help. [pause - congas] Archimedes kept thinking, thinking and thinking how he could check if the crown really only had gold. Eventually he went to take a shower, and when he got into the bathtub, which was full of water, he saw that a certain amount of water was thrown out. Then he connected the dots and realized that the volume of water that came out of the bathtub is equal to the volume of his body. With that, he saw that he could do the following: he could dip the crown in a bucket of water and see if the water that was thrown out had the same volume as two kilos of gold. Then when he had this insight, legend says that he ran out of the bathtub screaming eureka.

Lu - Ahh, so that's why he was naked.

Gláucia - Right. Literally, “eureka” means “I discovered”. With this story, “eureka” became a synonym for the moment of discovery, when you finally discover the solution to a problem you were working on. But, Lu, do you agree with that?

Lu - With that… what?

Gláucia - That we discover the solution to the problems? That what Archimedes did was a discovery? Well, more specifically, do you think scientific knowledge is discovered by researchers?

Lu - Huh, I think so? Isn't science about making discoveries?

Gláucia - It depends on how you view science. Note that this position is based on a previous idea, the idea that there is a truth to be discovered. But in general, this is the point of view we take, most of the time we talk about natural sciences. For example, when we talk about laws of nature, we assume that these laws exist, we just need to identify them. One person who thought more or less like this was Plato. That's why he wrote that story of the allegory of the cave, remember? Which we learn at school.

Lu - I think I remember that there were these people who spent their entire lives in a cave and only saw shadows on the cave wall, without realizing that there was a world out there.

Gláucia - That's it, that's the story. Plato said that the role of philosophy, or education as a whole, was to reveal this more complex level of reality. But he thought along the lines that there is an absolute truth, outside the cave. So, for him, studying and investigating the world is about making discoveries, getting closer to these truths.

Lu - Okay, but science is evolving, right? Yesterday we thought that some things were true and today we know that they are not.

Gláucia - Okay, but we might think that these stumbles in science are just approximations of this final truth. The important thing is that this truth exists. From this point of view, if we need approximations, it is because the tools we have at that moment are flawed. For example, I'll try to define Leo: he has brown hair, a beard, wears glasses and likes açaí. Now, this doesn't exactly define Leo, there's a lot more to it. But the fact that I have an incomplete description doesn't mean that Leo doesn't exist exactly as he is.

[pause]
Leo - [radio] Guys, just to confirm: I exist.
[play]

Lu - Okay, so these science updates don't mean that there isn't a scientific truth ready, waiting to be discovered. But if you're saying that, it's because not everyone agrees with Plato.

Gláucia - Not everyone agrees. There is this view that there is a truth and that science discovers it little by little... and there is another more or less opposite view, which almost says that science is invented.

Lu - Invented? This reminds me that I once saw a meme that showed a bunch of people flying and said “this is what the world was like before Isaac Newton invented gravity".

Gláucia - Well, it's not in the sense of inventing how nature works, it's more in the sense of inventing a representation, a description, suitable for it. We'll talk more about this throughout the episode, but the point is that the view of science that most people have is the same as Plato's: that, in science, there is a truth that we unveil through, between quotation marks, scientific discoveries. In fact, the vast majority of physicists, implicitly, also think this way with respect to their objects of study, and with good reason: when an astronomer identifies a new planet in a distant galaxy, she says that she has discovered a new planet. When a particle physicist talks about protons, quarks and positrons, he has no doubt that these things really exist.

[bass]

Leo - Now, there is an exception to this rule. The exception is those who work in quantum physics. Unlike other areas of physics, most of these researchers believe that quantum theory was not discovered, it was invented. And the question is: why? That's what we're going to try to answer in today's episode. My name is Leonardo Guerini, mathematician and Professor at the Federal University of Santa Maria.

Lu - I'm Luciane Treulieb, journalist and scientific promoter and I also work at UFSM.

Gláucia - And I'm Gláucia Murta, physicist and researcher at the University of Düsseldorf, Germany.

Leo - This is the podcast O Q Quântico. In today's first block we go back to the double slit experiment and try to answer the question: which slit did the photon go through? In the second block, we move on to philosophy and discuss what science being discovered or invented has to do with quantum theory. And the subject of block three is the linguistic difficulties that arise when we talk about quantum. Come with us that we are starting Episode 4: Is this real or is it just going on in my head?

[cat]

BLOCK 1: SUPERPOSITION AND TRAJECTORY ***********************************

[pause]
Lu - [radio filter] We're starting the fourth episode and it continues the discussion that started in episode 3, in addition to also making references to other previous episodes. So, if you haven't listened to them yet, we recommend that you pause now, listen, and then come back later.
[play]

Leo - At the end of the last episode, we were talking about the double slit experiment: we had a plate with two slits and we sent photons, or electrons, or atoms, one at a time towards this plate. To continue the discussion, let's say that we are doing the experiment with electrons. The electrons passed through the slits and reached the wall behind the plate. By marking the location where these electrons arrived, we form a pattern. What we find, and which is perhaps unexpected, is that even sending one electron at a time, the final result found on the wall is what we call an [radio filter] interference pattern, formed by several sets of marks, as if there were several slits, not just two.

Gláucia - So although the mental image we have, of the electron being something like a little ball, may not be so correct, because generating this interference pattern is the behavior of a wave, not a particle. But when it reaches the wall, it is detected in one place, exactly like a particle.

Lu - We talked about this a lot in the previous episode, right? That the electron has both a wave and a particle nature, because it has properties of both of these things. And this also applies to a photon, or an atom, or a molecule…

Leo - That! And then we can ask ourselves: where did the electron go? And during the trajectory… Did it behave like a wave or a particle? Because... if it hit the wall behind the plate, it's because it passed through it, it followed some path there. If during this period it behaved like a particle, particles have well-defined trajectories, which means that it passed through either the left slit or the right slit, just as, for example, a tennis ball would do. But if in the meantime the electron acted like a wave, it propagated more widely in space, passing through the two slits, as a sound wave would.

Gláucia -To try to answer what the electron's trajectory was, we can modify our experiment and place a detector behind each of the slits. And what we see is that these detectors are never activated at the same time. In other words, either the electron is detected passing through one slit… or another, never passing through both together.

Leo - The action of these detectors works as if it were a photograph of the electron in the slit region: either the photograph shows the electron in one slit, or it shows it in the other, never in both. In other words, in the photo, the electron appears as a particle, not as a wave.

Gláucia - And there's a catch. When we detect electrons in the slits, there is no way for them to continue moving forward. Detection is the end of the story.

Lu - So in this case they don't even reach the wall, right?

Gláucia - Right. Then we need some other strategy to try to understand the electron’s trajectory. An alternative is to alter our experiment once again by removing the detectors from behind the slits but scattering a handful of photons between the slits and the wall. Just to remember, the electron is the one that orbits around the nucleus of the atom, while the photon is the elementary particle of light, as if it were a small block of light. So when we place photons between the slit and the wall, the idea is not to measure the electron's trajectory directly... but rather to look for the traces that the electron left when it interacted with the photons.

Lu - So now it's as if instead of taking a photograph of the electron, we looked for the footprints that the electron left in the photons, is that it?

Gláucia - Exactly.

Lu - And what do these footprints say?

Gláucia - Well, get ready, we've arrived at a surprising part again. The footprints that the electron leaves on the photons actually show that it passed through a single slit and followed a specific path until it reached the wall. But… after several rounds of electrons being sent one by one, the pattern that forms on the wall is no longer the interference pattern, which was what told us that the electron acted like a wave. Instead, what we now find is simply two sets of marks, corresponding to each of the slits. And this is bizarre, because it indicates that the electron now acted like a particle.

Leo - In other words, if we leave the electrons alone, following their path without a detector, without a photon, without any disturbance… they generate an interference pattern, which is what waves do. But if we try to leave the electron's trajectory marked, directly or indirectly, it stops showing this wave behavior and acts like a particle all the time. It's as if it only shows this weird wave behavior when no one is watching!

Lu - What? Does the electron know when it is being observed?

Leo - More or less. Here the point is that quantum systems are super sensitive, and any interaction we have with them already disturbs their state. Both the detector and the photons that we scatter... or, as we joked, both taking a photo and leaving the electron's footprints marked... any of these interactions already disturb the electron and cause it to lose these wave properties. But we're going to go into more detail about this, this will be the topic of our next episode. For now let's focus on the electron's trajectory.

Gláucia - So here we reached a dead end. When we find the interference pattern and ask “which slit did the electron pass through?”, we don't get any clear answer, because whenever we try to answer that, just our attempt to answer the question already disturbs the system and causes the interference pattern to disappear.

Lu - Wait, let me see if I understand. If we see the interference pattern, we cannot know which slit the electron passed through. And if we detect which slit it passed through, we no longer have the interference pattern. My god, what a mess.

Leo - But there's more... because in the case where we don't see the interference, the best we can do is try to deduce, in an abstract way, the trajectory of the electron. As we have two slits and we know that the electron passed through them, our intuition says that there are 3 possible situations: the first, [plim] is that the electron only passed through the slit on the left; the second, [plim] is that the electron only passed through the slit on the right; and the third, [plim] is that the electron passed through both slits.

Gláucia - But we have investigated these possibilities before, when we placed detectors or photons in the electron's path. Assuming that an interference pattern was formed, the electron cannot have just passed through the left slit [aww], because every time we detect this happening, one way or another, the result marked on the wall is not an interference pattern; for this same reason, the electron cannot have passed through just the slit on the right [aww]. What remains is the last option, that it passed through both slits at the same time... but that can't be either [aww], because no electron ever fired both detectors. We never get a photograph of the electron in both slits at the same time.

Lu - Okay, so you're saying there were only 3 possibilities and none of them could happen? So what is the solution? Because this electron passed somewhere, right?

Leo - Well, that's the big question: what was the electron's trajectory? In this moment of doubt, we bring Pablo Saldanha back into the conversation, who is a Professor in the Department of Physics at the Federal University of Minas Gerais and also a regular guest of the podcast. But just listen to the answer he gave…

> **Pablo Saldanha:** So, there is a very natural question: what happens in this experiment? Does the electron pass through both holes or does it pass through just one hole? I don't know how to answer that question, I don't think anyone does.

Lu - Nobody knows? So quantum theory doesn't have an answer to this?

Gláucia - Well, here we need to be a bit careful. Quantum theory certainly describes this situation, it accurately predicts the pattern that we observe on the wall. But it's the theory. Here, Pablo is making reference to one of the great problems of quantum: how can we interpret, in intuitive terms, what quantum theory is saying? Because if we try to understand this in terms of our everyday phenomena, we return to wave-particle duality. Thinking of the electron as a wave will give you one answer, and thinking of the electron as a particle will give you another answer.

> **Pablo Saldanha:** Each one answers the question in a different way, but they give answers that are contradictory. [...] So I don't intuitively understand what is happening to the electron.

Gláucia - And the key word here is "intuitively". Because, if we are satisfied with an abstract answer, what the quantum formalism says is clear.

Lu - Can you help me remember what a formalism is?

Gláucia - Remember that in episode 2 you asked us how important it is to have a mathematical model to describe a phenomenon? Formalism is more or less that, it is the mathematics that describes a physical theory. We deduce some fundamental rules and derive the rest of the theory from them.

Leo - Thinking about a very simple example, imagine that type of question from third grade: [school track] "Johnny has five apples. If he eats two of them, how many apples will he be left with?" Here we don't think much, we just calculate 5 minus 2 and say that he ended up with 3 apples. But implicitly, this reasoning makes a series of relationships: we associate a number with the amount of apples we have and we associate "eating two apples" with "subtracting 2". These relationships, the way we model the problem, are our formalism in this case. Of course, this is an extremely simple example.

> **Pablo Saldanha:** The formalism of quantum mechanics is much more complicated. [...] But the fact is that you will have a set of mathematical rules, with mathematical equations, that will allow you to calculate in this case the probabilities of the experiments you are going to carry out. This set of rules is the formalism of quantum mechanics.

Lu - So what does quantum formalism say happens to the electron's trajectory?

Gláucia - It gives a somewhat strange answer. The formalism says that there is not just one trajectory passing through the left slit and another trajectory passing through the right slit. It says that there are infinite possible paths, because we can also have superpositions of these trajectories.

Lu - Ah, so here finally appeared this mysterious word, superposition, which you had already said before that it was one of the strange things about quantum. What does it mean?

Gláucia - Superposition is one of the most important phenomena in quantum theory. But when we try to explain in words what this means, we fall into the problem that Pablo talked about before: we don't have an intuitive way of doing this. To understand what the electron's trajectory was, I need to understand what a superposition of trajectories is. And although this is a mathematically well-defined concept, it is not clear what it means physically.

Leo - Going back to the example of apples, it would be more or less like this: [school track] it's easy to interpret what 3+1 means: it means that I had 3 apples and got one more. It's also easy to interpret what 4-2 means: it means I had 4 and ate 2 apples. But what does it mean to take the square root of the number of apples? [fiuu] What does it mean to calculate the logarithm of the number of apples? It is not clear how to do this translation. In other words, not all mathematical expressions have a simple or tangible interpretation.

Gláucia - And that's exactly what happens with the mathematical expression of a superposition. And then we find a great temptation to say that the superposition of passing through the slit on the left and passing through the slit on the right would be a trajectory that passes through both slits at the same time. But this is not correct. It's a simplification, but it ends up oversimplifying, to the point of being wrong. As we have already discussed, when we place detectors behind the two slits, they never detect the electron passing through both slits at the same time.

Leo - In fact, this is a misunderstanding that appears in several places. We often find, in pseudoscience content and even in science communication materials, that a quantum particle can be in two places at the same time, or, more generally, that it can do two opposite things at the same time. For example, listen to this quote from a YouTube channel:

[radio static]

> *“Powered by another powerful and counterintuitive concept: quantum superposition. Quantum superposition explains how particles can do two or a hundred or a million or trillion things at the same time.”*

[radio static]

Leo - Here we have another example:

[radio static]

> *“Quantum superposition implies that a particle can be in two places, two or more places or states simultaneously.”*

[radio static]

Gláucia - This last line is from the film ‘What the Bleep Do We Know!?’, which was quite successful about 15 years ago. I even watched this film in the cinema with my physics friends, back in our first year of bachelor, and at the time we thought it was a scientifically serious film, but today it is very clear that it is basically a lesson on how to talk about quantum theory in an extremely distorted way, not to say simply wrong.

Lu - Okay, I understand that the electron didn't pass through both slits at the same time. But then we can't answer where it went?

Leo - Well, although the mathematical formalism is clear, this is a question that quantum theory does not answer very well. This is the kind of thing that made the American physicist Richard Feynman, winner of the Nobel Prize in 1965, say [radio effect] “I think I can safely say that no one really understands quantum mechanics”. In fact, when we talked to Pablo, he said a sentence similar to this, about the trajectory of the electron:

> **Pablo Saldanha:** If knowing how to answer this question is important for me to say that I understand the phenomenon, then I don't understand the phenomenon.

Gláucia - So this becomes a philosophical question because it makes us look deeper and question the role of science itself. [congas] As we will see below, not being able to answer this type of question generated so much fuss among the founders of quantum theory that they ended up dividing the community into two groups, according to the role they attributed to science: the group of realists and the group of anti-realists.

[cat]

BLOCK 2: (ANTI)REALISM **

Leo - Ok, so to summarize what we have so far: in the double slit experiment, if we detect electrons only when they arrive at the wall, quantum theory explains well [plim] the interference pattern formed. The period of time, when the electron is between the slits and the wall, is the moment in which the electron is in the superposition state. But in this situation, the theory explains poorly [aww] which slit the electron passed through. If we try to answer this, again the theory explains well [plim] the situation in which we place detectors in the slits and see which slit each electron passed through. But in this case, the bad part [aww] is that this detection disturbs the electrons and they no longer form the interference pattern on the wall.

Gláucia - If you notice carefully, with Leo's summary, we see that the theory is great for dealing with detections. Or, using the analogy with photographs, the theory is great for explaining what we find when we take photos of the electron. And the part where the theory doesn't do well is when it comes to offering an interpretation for the moments when we weren't, in quotation marks, photographing.

Leo - So the dilemma is: if we don't take photographs, we don't know where the electron went. But if we photograph it, this interaction makes the electron act differently, not generating the interference pattern. So, there is a certain limitation that prevents us from knowing exactly what happened. But the question remains: is this a limitation of nature... or is it a limitation of quantum theory? And the answer… it depends. First, we need to answer what the role of a scientific theory is.

[pause]
Lu - [radio] Just a disclaimer: now we're going to talk about how to interpret quantum theory and science as a whole. But these open philosophical questions do not change in any way the fact that we do know how to control and manipulate quantum phenomena effectively, as we discussed in episode 2. In other words, none of this affects the functioning of quantum technologies and the results of experiments in the laboratory. Okay, now we return to the discussion about the role of a scientific theory. [play]

> **Patricia Kauark:** Quantum mechanics caused a lot of embarrassment, philosophical and scientific, by breaking with our so-called classical or

traditional conception of how we understand that the role of a scientific theory should be, right.

Gláucia - This is Patrícia Kauark, she is a Professor in the philosophy department at the Federal University of Minas Gerais. Patrícia graduated in physics and did her masters and doctorate in philosophy.

Patricia Kauark: Classically, we have this impression that theory mirrors, or should mirror, the world, should mirror reality.

Gláucia - Mirror reality. This is why this more classical point of view will say that quantum theory is problematic: because the theory says that the electron is in superposition, but we don't understand how this could be a reflection of reality.

Leo - The philosophical concept behind this position is called realism. Here, we listen to Osvaldo Pessoa Jr, Professor of philosophy at the University of São Paulo, who already appeared in our first episode.

Osvaldo Pessoa Jr.: And there are two basic attitudes in science. One is a realistic approach, it is to let yourself go beyond the observations and postulate models and portraits of what the world is like, behind the observations.

Leo - In other words, realism is a stance that expects science to go beyond the detections that are obtained in an experiment, or like the analogy we used, to go beyond photographs. A realistic person, in this sense, also expects science to describe a general picture, to explain nature as it is. Even when she is not being photographed.

Gláucia - In other words, realism means believing that a scientific theory really refers to the essence of reality, and that each element of the theory actually describes an element of nature. Maybe this point of view feels natural to you. In general, this is how we learn to think about science. It is no coincidence that Patrícia called this point of view classical.

Leo - Osvaldo told us that a few years ago he carried out a study together with a master's student of his, in which they interviewed several physicists and scientists in general. This study also confirmed a dominance of the realistic view.

> **Osvaldo Pessoa Jr.:** The general conclusion is that the attitude of scientists in almost all areas is realistic. They talk about quarks, no problem, as being something real, [...] curved space-time, dragging frames...

Gláucia - In other words, most areas of science and physics in particular assume the existence of various objects that are not directly observed, but which are widely accepted as things that do exist. This is the case with quarks, curved space-time, and so on. As Patricia says:

> **Patricia Kauark:** Realists will say that scientific theory is a discovery, it discovers that a theory unveils or discovers something that already exists in the world, right.

Leo - In other words, because they are considered real, when these studies appear for the first time, they are treated as discoveries: scientists discover that protons are formed by quarks; Scientists discover that spacetime is curved. And here we include that story that we brought up at the opening of the episode: Archimedes shouting eureka because he discovered the force of buoyancy.

Gláucia - But although realism seems quite natural, there is another possible view, which is called anti-realism. Here, Osvaldo:

> **Osvaldo Pessoa Jr.:** But there is also another attitude in science, which is the anti-realist attitude, which encompasses views such as positivism, Kantianism, instrumentalism, in short, these are views that consider that the great positive factor of science is that it is safe knowledge.

Gláucia - Wishing that science offers safe knowledge seems reasonable, right? So an anti-realist will take a more orthodox view, based only on observed data. In other words, returning to our analogy, anti-realism says that the role of science is limited to explaining photographs well. Trying to go beyond that and speculate about what happens to what has not been observed would be beyond the role of science.

> **Osvaldo Pessoa Jr.:** So this is a safer attitude, right? Wanting to guarantee that science will not reach any result that could be false because it will involve speculation about the physical nature of things, which we will not be able to prove... this safer attitude we call anti-realism.

Gláucia - So if you pay attention, this story of superposition and which slit the electron passed through when it generated the interference pattern, does not cause any problems for an anti-realist person, because all the data generated by the observations are well explained by the theory. Trying to physically interpret what it means for the electron to be in superposition is just another speculation... about an aspect of nature that we don't have access to.

Leo - In contrast to realism, this anti-realist view basically absolves quantum theory of not being able to interpret these strange things that end up appearing very well. A theory would merely be a tool to explain our observations, and not the phenomena themselves.

Lu - Don't worry, these terms are leaving me a little confused. In everyday life, we call a person who only sticks to the facts a realist. But here, we are saying that this is the anti-realist stance. And that?

Leo - And that. It may seem confusing, but the term "real" here refers to whether things actually exist or not. Realism is convinced that there is a reality independent of us interacting with it, and wants to speculate to describe this reality. From an anti-realist point of view…

> **Patricia Kauark:** Quantum mechanics should not describe the ultimate reality of things, but what it can at most describe is our interaction and our relationship with things or phenomena.

Leo - For Patrícia, the objective of science is to describe our interactions and our relationships with the world. So, every time we learn something new, we are inventing a new way of interpreting our interactions.

> **Patricia Kauark:** An anti-realist [...] will say that it is a scientific theory and much more an invention.

Leo - I think this line of reasoning is cool, because as Patrícia points out, seeing science as an invention implies that the scientific process is more or less similar to the artistic process.

> **Patricia Kauark:** So this is what will bring us much closer to art.

Gláucia - In other words, in the anti-realist view, both science and art are human creations that refer to the way we see the world. It makes no sense to demand that science really talk about the essence of nature, just as it makes no sense to demand that a painting be an objective portrait of its object (think of Picasso's paintings, for example). In both cases, we are dealing with interpretations of the world.

Leo - And as we already mentioned in the opening, despite the majority of scientists adopting a realistic stance…

> **Osvaldo Pessoa Jr.:** When it gets to quantum physics, it reverses. There's a tradition that comes with it, right? From the 1920s, to avoid speculation about what is happening behind the measurements, right?

Leo - In fact, quantum theory has challenged this realist paradigm since its foundation. Big names like Niels Bohr and Erwin Schroedinger were openly anti-realists. You may not know much about Schroedinger himself, but you've probably heard of his cat. [radio effect] In fact, we tell this story, which has everything to do with anti-realism, in our next quantum bit. Bohr, in particular, led a group that was very influential in the quantum community at that time. And one of the central ingredients of his vision was precisely anti-realism.

Gláucia - But not everyone agreed with Bohr.

> **Patricia Kauark:** Einstein, for example, was one who rebelled against this tendency to think that theory can no longer, no longer talks about the ultimate reality of things, but that it would be a way that we have to interact with the world, right.

Gláucia - Einstein was a convinced realist. He led, together with Bohr, one of the biggest scientific debates in history on the subject. He understood that the need to appeal to anti-realism was a limitation of quantum theory, a sign that something was missing from the theory. Einstein has a famous phrase criticizing the fact that for anti-realism all that matters are our observations: [radio effect] “do you really believe that the moon is only in the sky when you are looking at it?”

Leo - Although the question was very good, most researchers at the time agreed with Bohr. In fact, there's even a funny story about it. In 1927 there was the Solvay

Conference, in Belgium, on quantum physics, where a photo was taken that became known as [echo effect] “the most intelligent photograph in the world”.

Gláucia - It is a photo of the participants of this conference, 17 of the 32 participants had already won or were going to win the Nobel Prize (or even 2 Nobel Prizes as was the case with Marie Curie).

Leo - In the photo, they say that Bohr, who appears in the right corner, looks like he's laughing, while Einstein, sitting in the center of the photo, looks very serious. So legend has it that this would be a consequence of Bohr's anti-realist interpretation being more successful than Einstein's realistic ideas. In my opinion, even saying that Bohr looks like he's laughing is an exaggeration, but if you want to draw your own conclusions, we'll leave the photo on our website.
This discussion between realism and anti-realism in quantum theory is as old as the theory itself. But since the 20th century, to Einstein's sadness, anti-realism has been growing in the quantum community, as concluded by the research that Osvaldo mentioned earlier. To do a test, we here at O Q Quântico asked our interviewees how they position themselves in relation to this topic. Pablo gave a very clear answer.

> **Pablo saldanha:** A hundred per cent. I am anti-realist, let that be clear.

Leo - Patrícia also had no doubts.

> **Patricia Kauark:** As a Kantian, I'm a supporter there, I'm more on the side of the anti-realists. I think that quantum theory has really dealt a mortal blow to our claims regarding the truth of our theoretical constructions.

Gláucia - Well, despite all of Pablo and Patrícia's conviction, it is worth highlighting that there is a significant part of the scientific community that adopts a realistic stance. In fact, I myself think I fit into this group. And we won't go into that subject here, but you can imagine that a realistic interpretation of quantum mechanics won't be simple.

[With gas]

Leo - In any case, when it comes to quantum theory, both adhering to realism and anti-realism involve facing questions that take us out of our comfort zone.

[cat]

BLOCK 3: LANGUAGE ** *******

Lu - So, if I understand correctly, the dominant attitude within the community of quantum theory researchers is to consider that the theory does not propose explanations about reality, it is basically a mathematical language that describes the results of experiments. That's right?

Gláucia - That. Well, maybe this description sounds a little harsh on quantum, but we can look at it in two ways. From a pessimistic point of view, it's as if it didn't make sense to try to translate this mathematical language into a physical language, which we can understand in terms of photons and electrons. As is the case with superposition, we cannot give a physical interpretation to it. And not having this physical interpretation makes our understanding difficult, as we already discussed here in the last episode: we are unable to associate quantum theory with our day-to-day things and without being able to create a mental image of what the theory it says.

> **Barbara Amaral:** And then it's much more difficult for you to say, "Ah, I understand", because you didn't create the mental image, so you get the feeling that you didn't understand.

Leo - This speech was by Bárbara Amaral, a professor at USP, who is a physicist. But Patrícia Kauark, who is a philosopher, agrees with her:

> **Patricia Kauark:** In other words, I can point with my finger and say "here is a bottle of water" but I cannot point with my finger and say "here is an electron".

Leo - Now, we can also look at these gaps that exist between mathematical language and physical reality from an optimistic point of view: in a certain sense, it is as if the mathematical language of quantum theory could go beyond our physical understanding of the world.

> **Patricia Kauark:** We use a more elaborate language, a mathematical language, often more abstract, to precisely portray what would be the essence of things.

Leo - And this time, it's Bárbara who comes to complement Patrícia's speech.

> **Barbara Amaral:** So for us to really say "oh I see" we need mathematics. So to truly learn quantum physics, I need to know the mathematics that describes that system. Because the only way I'm going to have any more tangible contact with that is through mathematics.

Leo - In other words, although the anti-realist stance of the world does not worry much about interpreting the concepts that we find in quantum theory, it in a certain way becomes a compliment to the mathematical language developed by the theory.

> **Barbara Amaral:** On the other hand, see that our language, which is a mathematical language that we developed, is so powerful, that we can describe systems so well that we understand so poorly.

Lu - You have already repeated several times that one of those things that we understand so badly is superposition. This means that you can't describe exactly what the face of an electron in superposition looks like, right? But is there any way to put this concept in more familiar terms? Any analogies you think work well?

Leo - Well, we thought a lot about this and came up with an analogy to share here with you. Let's go back to the example that we've been discussing the entire episode, the trajectory of the electron in the double slit experiment. We know how to differentiate between passing through the crack on the left and passing through the crack on the right. The difficult thing is to say what the superposition of these trajectories means. So we will do the following: we will associate each trajectory with a cardinal point.

Gláucia - For example, let's consider two cardinal points, north and east, then we can use the north direction to represent the trajectory of the electron that passes through the left slit; and the trajectory of the electron that passes through the slit on the right, we can represent in the east direction.

Leo - From a physical point of view, we can only distinguish these two trajectories, going left or right (or, in terms of cardinal points, heading north or east). This is what we can observe in the experiment. However, quantum theory says that there are all possible cardinal points between them: not only north and east, but also, for example, northeast, north-northeast... And all these other directions would be what we call north and east overlaps.

Gláucia - In other words, it is as if our perception, which is not quantum, were a somewhat defective compass, which only works when we are moving north or east. Meanwhile, quantum systems have a much better sense of direction, being able to explore any possible direction, that is, any superposition of trajectories.

Leo - So here's the question: when we take the compass and walk in the direction that is exactly between north and east, which is the northeast direction... going in the northeast direction means that we are going north and east to the Same time?

Gláucia - On the one hand, we are even tempted to say yes, after all we end up at a point that is further north of our starting point and further east of our starting point... but if we want to be literal, follow going north and east at the same time would only be possible if we divided ourselves into two copies and then one copy of us goes north and the other copy goes east... which is physically impossible. Northeast is a cardinal point in its own right, so heading northeast is heading in a direction unlike any other.

Leo - Just as northeast does not literally mean “north and east at the same time”, being in superposition of passing through the left and right rift does not mean passing through both at the same time… [congas] a superposition of trajectories is an entirely different trajectory than others, even though our classical perception has difficulty interpreting this.

[cat]

CLOSING ** ************************

Gláucia - We learned a lot interviewing our guests for this episode, which also involved reflecting on our own relationship with science. So we wanted to finish by sharing two different views brought by two of our interviewees about quantum theory and its limitations.

Leo - On the one hand, we have Bárbara Amaral, who seems quite comfortable with the fact that the theory has elements that do not admit a natural physical interpretation, such as superposition.

> **Barbara Amaral:** In fact, I think it's cool that it's different, you know. [...] Of always leaving us with this flea behind our ears, of us never being able to marry our intuition with what happens there.

Leo - On the other side, we have Pablo Saldanha, who throughout our conversation showed great discomfort with this situation, but emphasizes that despite this the theory has practical consequences beyond any doubt.

> **Pablo Saldanha:** But the fact is that regardless of whether quantum theory does not describe to us what the fundamental entities are, it works to describe experiments and it works to produce technology. But what she's talking about, we don't know.

Lu - One of the cool things about this episode is that it leaves us reflecting on our own position on these issues. I myself kept thinking, am I more realist or anti-realist? Are scientific facts really real or just an invention that helps the world make sense? Here's the reflection...

Leo - [low] And to conclude, for several episodes now we have been saying that quantum phenomena are very different from what we encounter in our daily lives... in the next episode we will talk about why this happens and why, From a technical point of view, it would be so difficult to obtain a superposition of large objects, for example, a cat in superposition of alive and dead. In a way, we will even answer Einstein's question: is the moon in the sky when you are not looking at it?

[cat]

CREDITS ** ******************************

[identity track - drums, then bass and piano]

Gláucia - In the extra material on our website www.ufsm.br/oqquantico, you will find more information about the book that Osvaldo Pessoa Jr wrote with his master's student, Roseny Lisboa, about realism and anti-realism among physicists. There is also a reference to Patrícia Kauark's book on Quantum Theory and transcendental philosophy, as well as other references that we mentioned here, along with the transcription of the episode and the translation into English.

If you liked the episode, you can help by recommending the podcast to a friend who is interested in the topic. Also follow Q Quantico on Instagram @oqquantico and be sure to rate the podcast on your favorite podcast platform.

Leo - In this episode you heard excerpts from interviews with Pablo Saldanha, Patrícia Kauark, Osvaldo Pessoa Jr. and Bárbara Amaral. Many thanks to our interviewees.

In addition, we also used excerpts from the YouTube channel Giba Tavares and the film Who Are We, from 2004.

Lu - Q Quantico is presented by me, Luciane Treulieb, Glaucia Murta and Leonardo Guerini.

In addition to the three of us, Samara Wobeto and Vitor Zuccolo complete the team of podcast producers

The script for this episode is by Leonardo Guerini, with contributions from me, Gláucia Murta, and Samara Wobeto

The project was conceived by Leonardo Guerini and Gláucia Murta

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Thank you for listening and see you in the next episode!

[transition - cat]