» INTERVIEW

QUANTUM MECHANICS VS GENERAL RELATIVITY

Interview with Roger Penrose, emeritus professor of the University of Oxford, winner with Stephen Hawking of the Wolf Prize for physics, in 1988, for the formulation of the theorems on the Penrose-Hawking singularity.

The conference "Wave-function collapse as a resolution of a tension between General Relativity and Quantum Mechanics" by Sir Roger Penrose, emeritus professor of mathematics at the University of Oxford, was held on 25 September 2019 at the Bruno Touschek Auditorium of the INFN Frascati National Laboratories. During the seminar, professor Penrose illustrated his idea on the possibility of resolving the conflict between General Relativity and Quantum Mechanics.
The seminar was organized as part of the workshop "Is quantum theory exact? From quantum foundations to quantum applications" that took place at the INFN Frascati National Laboratories between 23 and 27 September 2019.
Roger Penrose is the author of important contributions to the mathematical physics of General Relativity and cosmology. He received numerous prizes and awards, including, in 1988, the Wolf Prize for physics together with Stephen Hawking for the theorems on the singularity of Penrose-Hawking, the Dirac Medal (1989) and the Einstein Medal (1990). We asked him to explain some of the founding ideas of his prolific mathematical thinking.

Professor Penrose, how could General Relativity and Quantum Mechanics be combined?
It's a common view that we have to make General Relativity subject to the laws of quantum mechanics, because big things are made from small things and quantum mechanics is a theory of the small, while General Relativity is a theory of the large. My view is different: I think Quantum Mechanics needs help. It's not a fully consistent theory and I'm more concerned with what you might call gravitising Quantum Mechanics than quantising Gravity. There are experiments which will show how Quantum Mechanics needs to be modified to be consistent with Einstein's theory of general relativity: that will be an important development in the future.

How can experimental physics do better to contribute to our knowledge of the universe?
One of the things where I believe experimental physics will change our view in a radical way is in experiments

» INTERVIEW

in which you see violations of standard Quantum Mechanics. So, if I have a body that could be in this or that place, Quantum Mechanics says that it could be in this and in that place at the same time. So there's the famous mental experiment proposed by Schrödinger who suggested you could have a cat (in a box), which was dead and alive at the same time. People call that Schrödinger's cat. Now, doing this experiment with a cat is not a good idea, but maybe you could use some very small object. Can you put the object in here and there at the same time? Or does that change the way we look at Quantum Mechanics and, ultimately, at physics as a whole? I think the most important experiments, which could be carried out in the near future, are those that stretch Quantum Mechanics to beyond the limits, which we have seen so far, and may well see deviations from standard Quantum Mechanics.

You have hypothesised that Quantum Mechanics may explain the mechanisms of the brain.
According to my view, conscious experience cannot be explained with simply classical ideas. But I'm more radical than many people: I believe it cannot even be explained by Quantum Mechanics as we currently understand it, but by the Quantum Mechanics that needs to be changed.
In current Quantum Mechanics, you could have an object in one place or another together at the same time. And, in my view, that won't happen for large objects. My view is that the way the conscious brain operates (I'm talking now about conscious experience) is not just using Quantum Mechanics, but it's where Quantum Mechanics needs to be extended in order that things don't remain in two places at once but they suddenly become one or the other. We need a theory of that: what people call collapse of the wave function. In my view, when we have such a theory we may perhaps be able to explain the working of the conscious brain better than we can now.

You and Stephen Hawking have given an important contribution to the physics of black holes. How has your collaboration started?
In the 1960s, there were observations of things called quasars, which were very mysterious objects that seem to produce a lot of energy. They were very small and they seemed to be the result of what is called "gravitational collapse".
People did not understand the concept of gravitational collapse very well. At the time there was a theory that seemed to have proved that when you have bodies that collapse gravitationally they would swirl around and come out again. And this was not known. I didn't know either. So I started to think about this problem very seriously. And it became clear to me that when the collapse reaches a certain point there is no help: the object would definitely collapse and form what we now call a singularity, a black hole. And then you would have these singular states where the curvature densities of space-time become infinite. So I wrote

» INTERVIEW

a theorem, which was published in Physical Review Letters, and I gave a talk about this, at King's College, London. According to the film ("The Theory of Everything", 2014, n.d.r.) Stephen Hawking was there, but he was not. However I gave a repeat of that lecture in Cambridge and Stephen Hawking was present. Afterwards I talked to Stephen and George Ellis privately and I discussed the techniques I was using in this proof of the black holes. Stephen Hawking then generalised these arguments to apply them to the Big Bang and to cosmology as a whole. He developed the arguments in clever ways and, then, we got together and used the arguments to have a theorem, which we published, after several papers of his own, in the Royal Society. This paper included most of the results we had and it had to do with cosmology and mainly with the big bang and black hole singularities. So that was the collaboration with Stephen. It was in the late 1960s.

What do you think of the black holes hair theory that Stephen Hawing proposed to solve the loss of information problem?

Stephen Hawking's main contribution to black holes was his theoretical discovery that black holes radiate. Previously, scientists thought that black holes were completely black: everything falls in. What Stephen Hawking showed was the use of combining theories from quantum field theory, Quantum Mechanics and General Relativity, to explain that black holes would have a very very slight radiation, which was called Hawking radiation. This was a very important theoretical concept.

The problem was that information would be swallowed by black holes and Stephen Hawing originally had the idea that black holes, effectively, swallow information. That's the expectation: I believed that myself and I thought he was correct.

Later on, in a bet he had with some other people, he changed his mind, and took the view that somehow, the information was not destroyed and came out again. I took the view that this was a mistake, that his first idea was the correct one and I continued to disagree with him on this. So we had many arguments about this. Somebody told me that he changed his opinion back again. I'm not sure about that. Certainly, in his later paper with other collaborators he was developing the idea that there were things like soft hair, and maybe radiations could carry the information out again. My own view was that he was correct in his first analysis and that the information is destroyed in black holes and that this is important for the sort of cosmological scheme, which had developed later.

Imagination is quite important in your work...

Imagination is very vital in physics. And I think when I was thinking about this collapse to a black hole, I tried to imagine what it was like inside it with the matter collapsing all around me and I think I got inspired by the very good books by George Gamow called *Mr. Tompkins in wonderland* and *Mr. Tompkins explores the atom*.

» INTERVIEW

In *Mr Tompkins in wonderland*, Gamow imagined the collapsing universe and there, all the bodies were coming inwards. And so the imagination of what it might be like of collapsing in a black hole was important to me, because I think I realised that it could not be simply a local thing: is it just that the equations blow up locally or is it something to do with the global feature? And that was an important realisation in the singularity theorem, which I developed with Stephen Hawking.

And this is only one example: imagination is in many cases where the ideas may be. I very often imagine geometrical pictures. I think very visually, so the ideas are spatial images and they can be very rigorous. The images can be not simply to get a general feeling but often they can be very precise in our geometrical insights. So imagination in all sorts of ways, either physical imagination or geometrical imagination or imagination that has to do with logics, is very important.

Do you think mathematical entities are real objects?

In my view, mathematical entities are real in the sense of the platonic world of things. For example, the number 3 is not a real thing, it's a concept, which is absolute. In the platonic view, there is a world, which is objective and not simply part of our creation and that exists independently of ourselves. This is not the world of physical reality, it's the world of mathematical reality.

It's very hard to understand how there could be laws of physics before there were conscious beings if it had to be conscious beings, who created mathematics. How do you create physical laws where there are not conscious beings? So I take the view that there is a world, the platonic world, the world of Plato's ideas, where the ideas of mathematical notions have a reality of their own. It's not the same as physical reality. And this world relates to physical reality and it relates to conscious experience. So, I tend to draw a picture where you have the physical world, the world of mentality and the world of mathematics: they are not the same as each other but they all interrelate with each other in important ways.

You are the author of many popular science books, written for a general audience. Do you think popularisation of science is an added value to science and to society?

I think there's a very important role in trying to make science accessible to the general public. This is why I wrote my first popular book, *The Emperor's New Mind*.

Once I heard on the radio a talk by Marvin Minsky and Edward Fredkin and they were talking about computers, and our computers would get cleverer and cleverer, much cleverer than us. And I could see where they came from, but I did not agree that we're just computers.

I had a reason for thinking otherwise from a course of lectures I went to when I was a graduate student in Cambridge, which were not to do with what I was doing. One was a course on mathematical logic that taught

» INTERVIEW

us about Godel's Theorem and about Turing machines, which is a theoretical underpinning of a modern computer. During that course, I was convinced that what we understand with our conscious understanding is not a computational thing, and so I held this belief for a long time, but I didn't think it was anything special. Only when I heard Marvin Minsky and Edward Fredkin talking about it I thought: look, that's not my view, there's something else going on, which is not computation. And I thought: well, I will write a book, trying to explain things in physics. But the ultimate thing was trying to show that in our conscious understanding we are doing something different from a computer. So the title of the book was *The Emperor's New Mind*. The title was based on *The Emperor's New Clothes*, the famous story about the emperor who had no clothes but since everybody had to believe what they thought they could all say: "Clap, clap, he has clothes!" And it took a little boy to see that he had no clothes. The idea was: it's obvious we're doing something other than a computer, but the story was somehow that we are told that it's all computers and we have to believe that. ■