Spring 2015

WHAT *IS* QUANTUM MECHANICS?

Maximilian Schlosshauer
University of Portland, schlossh@up.edu

WHAT *IS* QUANTUM MECHANICS?

By University physics professor Max Schlosshauer, when we asked: what is quantum mechanics, and can you explain it clearly to our readers?

I became a physicist because of quantum mechanics. Quantum mechanics tells us that the world is nothing like what we thought it would be. It breaks with every intuition we may have had, not only about nature but also about what science is ultimately about. It's like philosophy on steroids: you get all those mind-boggling, puzzling ideas, but unlike with philosophy, I can go up to my lab in Shiley Hall and do an experiment that proves that nature behaves in ways much weirder than the craziest philosopher could have ever dreamed of.

The theory of quantum mechanics, now a hundred years old, turned physics upside down. It tells us that every object in the world is like a box with many numbered doors. Each door represents a different kind of question you can ask about the box. So if you open a particular door — if you ask a particular question — you'll get an answer. But here's where things get funny. First, it is *fundamentally impossible* to predict what answer you will get. I don't mean that the answer is already contained in the box but you just haven't seen it yet; rather, the answer is *genuinely not determined until you open the door*. Second, it is *fundamentally impossible* to know what would have happened if you had opened a different door.

Now, in our familiar understanding of the world, we could just open door after door and get answers to more and more questions and thereby learn more and more about the box, just like asking your professor more and more questions. But quantum mechanics shows that learning the answer to a new question will typically force us to relinquish the answer to a previous question. We can never simultaneously know the answers to all the experimental questions we could pose to nature. This is a hard fact of our world. Of course, the idea that our knowledge of this world may be fundamentally limited is not new. But the point here is that the limitation is not in us; it is in nature itself.

Here's another strange feature. I'll give you one of those boxes with doors, and I'll get another box with doors numbered the same. Whenever you open a door with the same number as my door, we get the same answer. Magic? Not really, you may be tempted to say: after all, those answers could have already been in the box, like a pair of matching gloves. But I can prove that this explanation contradicts experimental data. (Come to my lab and I'll show you.) So your answers and mine are created on the fly just when we open the door, at places that may be solar systems apart, and yet they always match. How is this possible? No one knows.

What I've said so far makes it sound as if quantum mechanics is a nuisance, a road block on our path to knowledge of nature. But here's where things take another beautiful twist. It turns out that quantum mechanics actually gives us a much *richer* picture of reality. It does away with the clockwork picture of a universe in which everything plays out according to a script written at the time of the Big Bang. It replaces it with a universe full of possibility and with a genuinely open future. And on top of that, it is precisely those strange features of quantum mechanics I've described that have made possible everything we take for granted today. If quantum mechanics suddenly stopped working, there would be no computers, no cell phones, no CD players. The world would grind to a halt. In fact, today we are in the midst of a new technological revolution *fueled* by quantum mechanics. So-called quantum computers will be able to solve problems inaccessible to ordinary computers. Quantum mechanics also ensures that any eavesdropper on a communication will invariably be detected; banks and the military already use such quantum technology. Yet quantum mechanics was never developed with these applications in mind; they came only later, as a byproduct.

You may wonder why you never see any of this weirdness I've talked about, why the world around you looks and feels so normal, when quantum mechanics tells us it shouldn't. This is one of the areas of my research. The short answer is that for the weirdness to appear, things must be quite small, like atoms. When things get bigger, the weirdness becomes very difficult to observe. But because everything is made of atoms, the weirdness, in a sense, is still there. It's just that we need very refined experiments to see it.

You thought physics was about balls rolling down inclined planes? That's what I thought so too, until I met quantum mechanics. It changed my life and decided my career. I'm fortunate to be able to work on it with my students here at UP, and I'll sneak a little quantum mechanics teaser into every class I teach. Quantum mechanics also made me a humble scientist, because it tells me that while nature may at some point be fully *describable*, nature will never be fully *knowable*. But quantum mechanics is also empowering, for it tells us that our interaction with the world — our choice of which door to open, which question to ask — brings forth genuinely new events that were in no way determined by anything that has gone before. And thus every one of our actions helps write nature's eternally unfinished story. Me, personally, I draw great inspiration from such a participatory universe.

From a series of paintings of Salzburg, Austria, by Father Mark Ghyselinck, C.S.C.