“How Come the Quantum”
By John Archibald Wheeler

What is the greatest mystery in physics today? Different physicists have different answers. My candidate for greatest mystery is a question now century old, “How come the quantum?” What is this thing, the “quantum”? It’s a bundle of energy, an indivisible unit that can be sliced no more. Max Planck showed us a hundred years ago that light is emitted not in a smooth, steady flow, but in quanta. Then physicists found quantum jumps of energy, the quantum of electric charge and more. In the small-scale world, everything is lumpy.

And more than just lumpy. When events are examined closely enough, uncertainty prevails; cause and effect become disconnected. Change occurs in little explosions in which matter is created and destroyed, in which chance guides what happens, in which waves are particles and particles are waves.

Despite all this uncertainty, quantum physics is both a practical tool and the basis of our understanding of much of the physical world. It has explained the structure of atoms and molecules, the thermonuclear burning that lights the stars, the behavior of semiconductors and superconductors, the radioactivity that heats the earth, and the comings and goings of particles from neutrinos to quarks.

Successful, yes, but mysterious, too. Balancing the glory of quantum achievements, we have the shame of not knowing “how come.” Why does the quantum exist?

My mentor, the Danish physicist, Niels Bohr, made his peace with the quantum. His “Copenhagen Interpretation” promulgated in 1927 bridged the gap between the strangeness of the quantum world and the ordinariness of the world around us. It is the act of measurement, said Bohr, that transforms the indefiniteness of quantum events into the definiteness of everyday experience. And what one can measure, he said, is necessarily limited. According to his principle of complementarity, you can look at something in one way or in another way, but not in both ways at once. It may be, as one French physicist put it, “the fog from the north,” but the Copenhagen interpretation remains the best interpretation of the quantum that we have.
Albert Einstein, for one, could never accept this world view. In on-again, off-again debates over more than a dozen years, Bohr and Einstein argued the issues—always in a spirit of great mutual admiration and respect. I made my own effort to convince Einstein, but without success. Once, around 1942, I went around to his house in Princeton to tell him of a new way of looking at the quantum world developed by my student, Richard Feynman.

Feynman pictured an electron getting from point A to point B not by one or another possible path, but by taking all possible paths at once. Einstein, after listening patiently, said, as he had on other occasions, “I still cannot believe God plays dice.” Then he added, “But maybe I have earned the right to make my mistakes.”

Feynman’s superposed paths are eerie enough. In the 1970s, I got interested in another way to reveal the strangeness of the quantum world. I called it “delayed choice.” You send a quantum of light (a photon) into an apparatus that offers the photon two paths. If you measure the photon that leaves the apparatus in one way you can tell which path it took.

If you measure the departing photon in a different way (a complementary way), you can tell if it took both paths at once. You can’t make both kinds of measurements on the same photon, but you can decide, after the photon has entered the apparatus, which kind of measurement you want to make.

Is the photon already wending its way through the apparatus along the first path? Too bad. You decide to look to see if it took both paths at once, and you find that it did. Or is it progressing along both paths at once? Too bad. You decide to find out if it took just one path, and it did.

At the University of Maryland, Carroll Alley, with Oleg Jakubowicz and William Wickes, took up the challenge I offered them and confirmed that the outcome could be affected by delaying the choice of measurement technique—the choice of question asked—until the photon was well on its way. I like to think that we may one day conduct a delayed-choice experiment not just in a laboratory, but in the cosmos.

One hundred years is, after all, not so long a time for the underpinning of a wonderfully successful theory to remain murky. Consider gravity. Isaac Newton, when he published his monumental work on gravitation in the 17th century, knew he could not answer the question, “How come gravity?” He was wise enough not to try. “I frame no hypotheses,” he said.
It was 228 years later [that] Einstein, in his theory of general relativity, attributed gravity to the curvature of space-time. The essence of Einstein’s lesson can be summed up with the aphorism, “Mass tells space-time how to curve, and space-time tells mass how to move.” Even that may not be the final answer. After all, gravity and the quantum have yet to be joined harmoniously.

On the windowsill of my home on an island in Maine, I keep a rock from the garden of Academe, a rock that heard the words of Plato and Aristotle as they walked and talked. Will there someday arise an equivalent to that garden where a few thoughtful colleagues will see how to put it all together and save us from the shame of not knowing “how come the quantum”? Of course, in this century, that garden will be as large as the earth itself, a “virtual” garden where the members of my imagined academy will stroll and converse electronically.

Here, a hundred years after Planck, is quantum physics, the intellectual foundation for all of chemistry, for biology, for computer technology, for astronomy and cosmology. Yet, proud foundation for so much, it does not yet know the foundation for its own teachings. One can believe, and I do believe, that the answer to the question, “How come the quantum?” will prove to be also the answer to another question, “How come existence?”

Einstein explained the “why” of gravity, but even that may not be the final word. That’s a description, not an explanation.

Perhaps physicists will one day solve the “why” of the quantum. Nice reference to the Internet.

Quantum physics, foundation for so many fields, is itself built on a mystery. He thinks we can understand meaning through science—a purely descriptive field.

Conclusion