

Shining A Light on a Dream

What is quantum physics fundamentally about?

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by **MARC KAUFMAN**

Conference Idea: What is quantum physics fundamentally about?

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At the dawn of the 20th century, Philipp Lenard shone a light on a metal surface and noted a surprising relationship between the characteristic of the light and the electrons released when the beam hit the metal. While increases in the *frequency* of the light produced increased energy in the electrons released, increases in the *intensity* of the light did not. The prevailing theory of light at the time, a wave theory, could not account for this non-intuitive result: after all, shouldn't "more" light create more energetic electrons?



WOJCIECH H. ZUREK
Los Alamos National
Laboratory

Four years later, Albert Einstein, in the first of his five papers published in 1905, used Lenard's experiment and Max Planck's mathematical constant to apply a particle theory to a radiation field. As a result, Einstein formulated the theory of wave-particle duality and shone a new light on the relationship between a nascent physical theory and our physical reality: Quanta – or photons, as the discrete packets of energy

would soon be named – were real and not, as Planck had suspected, simply a way to describe what happens when energy interacts with matter.

But while this conclusion opened a new world of possibilities described by what came to be called quantum mechanics, it also launched a quest to reconcile this new physics with everything we thought we knew about the world around us – information we had gathered using Newtonian or Classical physics to make sense of our surroundings.

For Einstein, this search was profoundly disturbing and, ultimately, unsatisfying, haunting him through the rest of his life. "All my attempts ... to adapt the

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- Roderich Tumulka

theoretical foundation of physics to this (new type of) knowledge failed completely. It was as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere, upon which one could have built," Einstein wrote in his autobiographical notes from 1949. "This double nature of radiation (and of material corpuscles) is a major property of reality, which has been interpreted by quantum mechanics in an ingenious and amazingly successful fashion. This interpretation, which is looked upon as essentially final by almost all contemporary physicists, appears to me as only a *temporary way out*" (emphasis added).

The Dream Stuff is Made Of

So what is quantum mechanics fundamentally about? Is it correct? Is it complete? Does it describe the world around us, at least to the extent that we can agree the world around us constitutes an objective reality? Or was Einstein ultimately right in thinking that quantum mechanics is merely a stopgap – the best we can do until we arrive at a successor theory that is more easily reconciled with our perceptions and what we thought we knew about the laws of physics?



RODERICH TUMULKA
Rutgers University

More than 100 years after Einstein's *annus mirabilis*, and more than 50 years after he died still wondering, "What are light quanta?" physicists continue to wrestle with the precise nature of the relationship between quantum mechanics and "reality" – and how best to explore, test, and illuminate that relationship.

"Quantum theory: the dream stuff is made of," muses Wojciech H. Zurek, a physicist and Laboratory Fellow at Los Alamos National Laboratory in New

Mexico, and one of the world's leading authorities on quantum theory, chuckling as he quotes a slogan he likes very much, even if he can't cite its origin. "The quantum wave function is so elusive ... it changes when you try to pin it down, so in some sense it's not a candidate for reality. On the other hand it's the only thing we've got."

Heinz-Dieter Zeh, a theoretical physicist, a pioneer of the theory of decoherence, and a founder of the "many minds interpretation," opts for a more declarative response when asked whether or not quantum mechanics is about reality.

"Definitely yes," answers the professor emeritus at the University of Heidelberg in Germany. "How else could it be relevant for physical properties and phenomena? This statement holds in spite of the necessarily hypothetical nature of any concept of reality."

Roderich Tumulka agrees. "I believe that there is an objective reality," he says. "I further believe that any reasonable theory about how quantum mechanics works must be about such an objective reality. Even more, I believe that space, time and matter must be categories of that objective reality."

Tumulka, a mathematical physicist at Rutgers University in New Jersey, acknowledges that the paradoxes faced by Einstein, Niels Bohr, and the rest of the scientists who laid the groundwork for quantum mechanics pushed some to question the very existence of an objective reality. Not being able to interpret quantum mechanics in a way that matched the experimental facts led to claims that it was "impossible to explain how quantum phenomena work, to say how electrons behave inside an atom, to say what really goes on."

But Tumulka believes that contemporaneous theories such as Bohmian mechanics and Ghirardi-Rimini-Weber Collapse Theory have indeed overcome the paradoxes faced by the first and subsequent quantum physicists, and "provide a coherent story about objective reality in agreement with the empirical facts of quantum mechanics."

Further, Tumulka finds the idea that there exists no objective reality "incomprehensible, and can't attach any clear meaning to it," adding, "I can imagine many ways the world could be, but I can't imagine any hypothetical world for which it would be appropriate to say that there is no objective reality."

One of the realities of the quantum world, Zurek says, is that quantum objects change when measured. It is an unavoidable consequence of the act of measuring. This might be counterintuitive to those whose experience is limited to objects in the classical world, so much so that we might look for an alternate theory to explain reality, but, as Zurek reminds us, "there's nothing else to make stuff of."

The Measurement Problem

Zurek, who studied physics in Krakow in his native Poland and then in Austin, Texas before arriving at Los Alamos as a J. Robert Oppenheimer Fellow in 1984, is fascinated by the fundamental tensions in quantum theory, and the discomfort they cause in those who spend their lives working with it.

"Why is a theory that seems to account with precision for everything we can measure still deemed lacking?" Zurek asks in the introduction to his 2002 essay *Decoherence and the Transition*

from *Quantum to Classical—Revisited* (emphasis in the original).

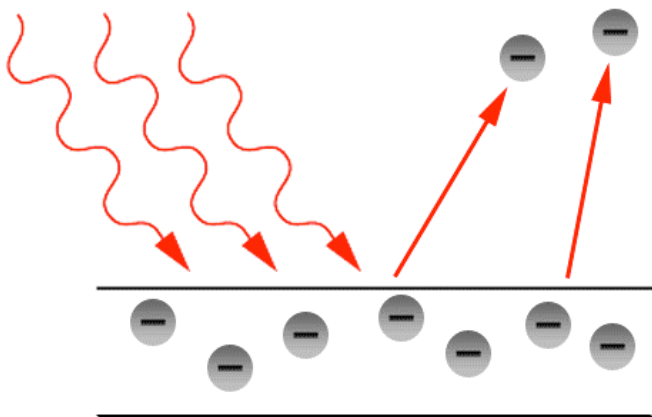
The answer, Zurek suggests, is that the act of measurement itself proves problematic in a variety of ways, most acutely when the object we are trying to measure is said to have a state in which it is occupying more than one location at the same time. In other words, quantum theory demands that an object can be in two places at once – something that in everyday life is simply not possible.

"At the root of our unease with quantum theory is the clash between the principle of superposition and everyday classical reality in which this principle appears to be violated," Zurek writes.

But the appearance of contradiction is just that – an appearance. It does not necessarily mean that the predictions of quantum theory are in conflict with the reality of the macroscopic world around us.

"We've gotten used to believing our senses, and our senses are not a fine enough probe of physics," Zurek says. "Our senses did not evolve for the purpose of verifying quantum mechanics, rather they developed through a process in which survival of the fittest played a central role. And when nothing can be gained from prediction, there is no evolutionary reason for perception."

So Zurek, Tumulka, Zeh and their colleagues around the world continue to burn the candle at both ends, searching for an interpretation of quantum mechanics that best shines a light on the dream stuff is made of.



PHOTOELECTRIC EFFECT In the early twentieth century, Philipp Lenard noticed an unexpected relationship between the frequency of light shone on a metal and the energy of the electrons thereby released.