

address the difficult moral question of whether they should build an atomic bomb. The fact is, they did. But in any case, *My Dear Li* shows that Heisenberg avoided addressing his own moral dilemma.

Writing to Otto Hahn in 1948, Lise Meitner forcefully stated, “It is very clear to me today that I committed a great moral wrong by not leaving in 1933, since in the last analysis by staying I supported Hitlerism.” I believe the same was true of Heisenberg, who not only remained but worked with the Nazi

regime. Heisenberg believed strongly in the purity of the scientific enterprise, the excellence of German institutions, and the importance of their preservation. Those convictions allowed him to identify with Nazi Germany and justify to himself his collaboration.

Silvan Schweber

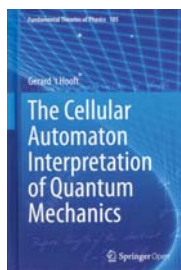
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[Editors’ note: With sadness, we inform our readers that Silvan Schweber died on 14 May 2017.]

The Cellular Automaton Interpretation of Quantum Mechanics

Gerard ‘t Hooft

Springer, 2016. \$59.99 (298 pp.). ISBN 978-3-319-41284-9



When I was a particle-physics graduate student back in the 1980s, Gerard ‘t Hooft was a hero to me and my fellow students. A recognized grand master of quantum field theory, he had established in his PhD thesis gauge theories as a usable tool—a tour de force later rewarded with a Nobel Prize—and then went on to contribute a long series of startling, deep, and diverse insights. Yet when we finally heard ‘t Hooft deliver a lecture to our department, we were baffled by his arcane choice of subject: quantum mechanics inside a black hole. It seemed totally disconnected from what everybody else was working on. Thirty years later everybody knows about the black hole information paradox, which has led to hundreds of papers and some profound insights and is even the topic of popular science books.

With *The Cellular Automaton Interpretation of Quantum Mechanics*, ‘t Hooft has managed to surprise me once again by proposing a new way of looking at that branch of physics. His stated goal is to show that Albert Einstein was right to think that there is no fundamental randomness in nature—a conclusion contrary to the belief of the founding fathers of quantum mechanics and of most contemporary working physicists, and contrary to what is taught in any quantum mechanics class.

Of course, the predictions of quantum mechanics have been experimentally verified beyond any reasonable doubt, and ‘t Hooft is well aware of the difficulties encountered by any attempt to derive those predictions from an underlying deterministic theory. In fact, he takes the view that any modification of the basic equation of quantum mechanics—the Schrödinger equation—should be rejected. Yet he also proposes that the apparent randomness of the quantum world can be explained deterministically.

In his new book, ‘t Hooft manages to reconcile the apparent contradiction by exploiting a simple yet deep observation: If one could identify at all times the basis in which the evolving state of the system is not a superposition, then it would be possible to extract fully classical predictions. In particular, it would be possible to avoid the collapse of the wavefunction. According to ‘t Hooft, an “ontological” preferred basis can exist in which the state of the universe evolves deterministically. The reason why we perceive randomness in the universe is that we are using the “wrong” basis.

That interpretation, argues ‘t Hooft, avoids the pitfalls of previous attempts to derive quantum mechanics from underlying deterministic “hidden variables” because it abandons freedom of choice. For example, in the famous

Einstein-Podolsky-Rosen paradox, the set of possible outcomes of a measurement depends on the observable that is being measured. The paradox arises because a deterministic explanation of all possible measurement outcomes for a given system would require the system to have mutually incompatible properties before the measurement is performed. In ‘t Hooft’s “superdeterministic” interpretation, universal conservation laws require that out of all possible measurements, only one can actually happen. The paradox therefore disappears.

The Cellular Automaton Interpretation of Quantum Mechanics is divided into two parts. The first contains few equations and only some simple calculations—examples worked out at critical junctures to make arguments concrete and understandable. The second part is a collection of computations that demonstrate explicitly how ‘t Hooft’s idea may be realized in practice. That is where cellular automata come in: ‘t Hooft’s preferred basis, like a cellular automaton, evolves in discrete time steps with an unobservably small scale (perhaps set by the Planck length).

At the beginning of the book, I couldn’t help but experience disbelief. Yet as I delved into it, I started wondering, “What if ‘t Hooft is right after all?” He is well aware that he is treading a minefield. Somehow, he manages to levitate a few inches above ground, supported by a combination of practical computations and candid admissions of what he does and does not understand.

So will ‘t Hooft once again manage to pull off a magic trick, as he did in our department 30 years ago? Will everybody in 20, 30, or 50 years study quantum mechanics based on the ‘t Hooft interpretation? That is unlikely, yet it is hard to rule out the possibility. Certainly, if even a small fraction of the ideas proposed in the book turn out to be correct, then this most recent opus will dwarf all other contributions ‘t Hooft has given to science. For the time being, the best we can do is enjoy this beautifully written, entertaining, and provocative book and wonder whether we are prepared to change our mind about a basic and firmly held belief: The laws of Nature are fundamentally random.

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