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A Midrash Upon Quantum Mechanics

By DIETRICK E. THOMSEN

"And thus we see how clever Niels Bohr was to die before the invention of the Copenhagen Interpretation."
— Arthur Komar, Yeshiva University

The Copenhagen Interpretation of quantum mechanics has become the standard way of explaining the physical and philosophical meaning of the mathematics of microscopic behavior. It developed from the thought of people who attended the Institute for Theoretical Physics of the University of Copenhagen during the 40 years that Niels Bohr directed it, from 1920 to 1962. Bohr took a large part in developing the Copenhagen Interpretation, and he didn't escape all controversy over it (although the quote above is a bit of an exaggeration). Bohr did die before the experimental and theoretical developments that have transposed the debate over the appropriateness and adequacy of the Copenhagen Interpretation into a new key, and he may well have been lucky to have escaped when he did.

"There is no authoritative codification of CI [the Copenhagen Interpretation]," write T. Görnitz and C. F. von Weizsäcker of the Max Planck Institute in Starnberg, West Germany, in their formal presentation to the recent Loyola Conference on Mathematical and Interpretational Problems in Relativistic Quantum Theory, "and under the conditions of its origin there probably could not be one. . . . All prominent authors of the time who wrote on these questions, like Bohr, [Werner] Heisenberg, [Wolfgang] Pauli, J[ohn] v[on] Neumann on one side, [Albert] Einstein and [Erwin] Schrödinger on the other, fell, so we feel, into some stammering when they tried to express their own positions."

Nevertheless there is what might be called a Copenhagen attitude. It concentrates on observable phenomena, makes statistics and probability central to its understanding, considers quantum mechanics primarily a theory of knowledge or information and becomes a kind of *physica negativa* (analogous to a *theologia negativa*) in trying not to say too much about things that can't be seen or felt. For example, it doesn't much care whether the orbits of electrons in atoms are real or not and, in fact, tends to regard them as unreal. It appears in most textbooks as the standard way of looking at things.

From the beginning, critics have said that CI is unrealistic and too positivistic, and gives too little information to be a complete physical theory. Einstein and Louis de Broglie put forward alternatives that they believed were more realistic or more complete. In the opinion of many physicists, recent experiments have finally blown both of those suggestions out of the water, but the same experiments bring quantum mechanics out of the realm of the unseen and untouchable (atoms, nuclei, elementary particles) and into the realm of macroscopic objects we can handle — up to and including the whole universe itself.

In consequence, the need for viable interpretations of quantum mechanics that will come to grips with underlying reality and will try to deal with the problems of applying a basically statistical mathematics to the fate of single objects is even more strongly felt. Several new interpretations have arisen in recent years, and one of the purposes of the Loyola conference was to discuss the adequacy and relation to CI of some of them, particulary the Transactional Interpretation of John G. Cramer of the University of Washington in Seattle.

Interpretational problems are not new in physics, but quantum mechanics raises them to new levels of complexity. How one translates mathematics into physics and the semantic problems involved with the words chosen to effect the translation are questions that accompany any physical theory. Cramer, Görnitz and Weizsäcker use Newton's second law as an example. "[We] define the physical meaning of the mathematical quantities *t, x, F, m* by means of words which are available in the English vernacular: time, body, force, etc.," Görnitz and Weizsäcker write. "But are we sure what these words mean? Every student of the empirical foundations of classical mechanics becomes aware of the difficulty of defining them unambiguously."

In quantum mechanics the ambiguities are far worse. Newton's laws deal in linear and quadratic equations that tend to give a definite object a definite and unique course of action. The basic equation of quantum mechanics is a wave equation that seems to imply a multiplicity of possible courses for a single object at the same time. What does this wave equation represent? How do we translate it into physics? The attempts at solution get into basic problems of reality, consciousness, time and measurement.

Louis de Broglie first put the waves into quantum mechanics with his theory of matter waves: that every piece of matter has a wave associated with it or a wave aspect to its nature. From this flow both the uncertainty principle of Heisenberg and the Schrödinger equation, the basic dynamical equation of quantum mechanics, which is a wave equation. This wave equation or state vector, as it is called from a mathematically equivalent but formally different method of formulating the equation, is supposed to describe the physical state of a system under consideration. It seems to offer a multiplicity of possible states for the system to be in.

Yet if someone makes a measurement on this system, any measuring apparatus will give a definite reading — in other words, one choice out of all the possibilities. In the traditional Copenhagen language, what the measurement does is to collapse — or, in less dramatic terminology, to reduce — the state vector. It chooses one out of all the possibilities. The wave function represents nothing physical; it represents the observer's knowledge of the state of the system, and its collapse reduces a host of knowable possibilities to a single one.

In contrast, those who think of themselves as "realists," starting with Einstein and de Broglie and now including Cramer, want the wave function to represent something physical, and they want it to make predictions without the intervention of this *deus ex machina*, the observer.

Here is the importance of the observer in traditional quantum mechanics under the Copenhagen Interpretation. In a sense, the observer picks what happens. One of the unsolved questions is whether the observer's mind or will somehow determines the choice, or whether it is simply a case of sticking in a thumb and pulling out a plum at random. The question also arises whether the measurement creates a new state or whether it records a state (or *the* state) of the system just prior to the measuring action. Eugene P. Wigner of Princeton (N.J.) University and Louisiana State University in Baton Rouge, who has had a great deal to say on these topics in the past, remarked in the discussion: "The wave equation of a system cannot be determined by a measurement. Measurement creates a state, but the initial state [that is, before the measurement occurred] cannot be known."

These questions of what the observer does and what the observer can know illustrate what nearly everyone considers the major incompleteness of traditional quantum mechanics: It postulates this observer whose action is crucial, but it does not describe the observer, nor does it include the observer in the system. The recent reinterpretations, including Cramer's and one by David Deutsch of Oxford University, attempt to bring the observer into the theory and so try to solve the problem of uniqueness vs. statistics and how choices are made.

Weizsäcker and Görnitz want to bring the observer into the Copenhagen Interpretation, and for that purpose they have worked out an abstract quantum mechanics divorced from ordinary space and time and particles. With it they can talk about quantum states of the observer and apply quantum mechanics to states of mind. "A quantum state of an observer — is it a meaningful statement?" Weizsäcker asked the Loyola conference, which met at Loyola University in New Orleans.

To make it one he has to do away with the distinction between mind and matter that René Descartes set at the basis of modern philosophizing. "There is no distinction between substances called mind and matter," Weizsäcker said. As he conceded, this involves a "profound question of self-knowledge. As soon as I wonder what I feel in this moment, I disturb my own feeling."

This cancellation of fundamental philosophical distinctions drew objections, exemplified by Edward Teller of Lawrence Livermore (Calif.) Laboratory: "I have some concept of looking at myself as an object. There is a difference between looking at myself as a piece of matter and looking at myself as a spirit or mind."

A less abstruse approach is Cramer's Transactional Interpretation, which uses an analogy between quantum mechanics and ordinary electrodynamics. The wave, in this case, is physically real, something emitted by an object under consideration, as if the object were a radio transmitter. In electrodynamics, the mathematics provides for two kinds of waves — a "retarded" wave, which goes forward in time, and an "advanced" wave, which goes backward in time. (The terminology sounds like the opposite of what it should be, but that's the custom.)

In ordinary electrodynamics we throw away the wave going backward in time as unphysical, but Cramer's interpretation is "atemporal" or four-dimensional; it treats time exactly as the three spatial dimensions. Going backward in time is no different from going left instead of right. In this view a physical interaction consists of the original object, the "emitter" sending a wave forward in time until it encounters another object or objects, the "absorber." The absorber sends a wave backward in time, and when this reaches the emitter, a transaction — as Cramer puts it, a handshake — has occurred, representing some physical happening between them.

Although this action is described sequentially, and human beings have an ingrained tendency to take sequence as something temporal, this is not a temporal sequence. "Since the transaction is atemporal, . . . it makes no difference to the outcome or the transactional description if separated experiments occur 'simultaneously' or in any time sequence," Cramer writes in the July 1986 REVIEWS OF MODERN PHYSICS. As a result of the atemporal quality of the transaction, the problem of the various possibilities offered by the state vector is sorted out, because the interaction with each absorber chooses one of them and this is really done before we consider the transaction. The transaction is complete between the two objects; the observer has no special meddling to do.

Cramer's Transactional Interpretation has the same uncertainty principle and the same statistical interpretation of possibilities as the Copenhagen Interpretation. However, in it, all physical processes have equal status; the observer is not special. The fundamental interaction is the transaction, in which the wave equation represents something real — its correspondence with knowledge is fortuitous. On the question of positivism — what we can say about realities — a distinction is made between observable quantities, which are firm predictions of the theory, and inferred quantities, which are used for pedagogical and explicatory purposes.

Görnitz and Weizsäcker believe that the newer interpretations can be translated into the Copenhagen Interpretation, given the right assumptions about CI and the right semantic "dictionary" to accomplish the translation. They say that in terms of the Copenhagen Interpretation, the Transactional Interpretation treats all events as if they were already in the past — that is, by a definition of the past as the area where choices already have been made.

Time and time sequence, past and future, are serious problems in all of physics. Time is something that everyone apprehends, yet great minds — Isaac Newton, for example — have had difficulty defining it. So Görnitz and Weizsäcker quote St. Augustine of Hippo (A.D. 354-430): "If you do not ask me what is time, I know it; when you ask me, I cannot tell it."

The problem is compounded in quantum mechanics, because the equations are time-symmetric: They can go either forward or backward in time. Life, on the macroscopic level at least, never goes backward in time. This has led a lot of people to worry about the many possibilities and probabilities that are formally present in the mathematics but were never realized in the past. It has also led them to try to derive an "arrow of time" or the Second Law of Thermodynamics, which contains such an arrow, from the basic principles of quantum mechanics or at least in a way compatible with them.

Görnitz and Weizsäcker try to solve the problem by defining past and future in terms of *now*, the only moment we ever experience, which is, as the theologians say, our only contact with eternity. "The past consists *now* of facts; the future consists *now* of possibilities," Weizsäcker said in his oral presentation. In other words, the past is a memory, and the choices have been made; the future is yet to be realized. "CI presupposes this everyday phenomenology of time."

Cramer and Deutsch sound strange because they do not make that presupposition. However, just as Görnitz and Weizsäcker describe the Transactional Interpretation in CI terms as regarding everything as in the past, which is already fact, they also describe Deutsch's interpretation as regarding everything as in the future, the realm of open possibility.

According to Görnitz and Weizsäcker, in Deutsch's interpretation the problem of collapsing the wave function from many possibilities to one does not arise because all its possibilities are realized. Only one, however, occurs in our universe. The others happen in other universes that exist parallel to ours. This interpretation supposes the parallel existence of a multitude of universes or the branching of one universe into many with every physical action. As Görnitz and Weizsäcker observe: "But for the single observer it is unknown in which 'world' he will find himself after the next interaction process."

Thus physics can tell the difference between past and future, between the realm of fact and that of possibility. Knowing that may help solve some of the difficulties involving possibilities, choices and facts, but a serious difficulty still remains: The now, the sliding moment in which we know what we know and do what we do, the boundary between chosen facts and possibilities still to be chosen, remains undefined. On this Weizsäcker quoted Einstein: "The now remains unexplained by physics." □