INTERLUDE

Newton to Heisenberg

More than 50 years have passed since the wave and particle models merged to become a new model of the physical world. In the early days of this century, physicists voiced strong arguments for and against wave-particle duality and its interpretations. Now, the arguments have become less emotional: the concepts, less unsettling. Passing years and new generations of physicists have a way of turning a revolutionary thought into a tradition; the new physics into the old physics. In the midst of this settled acceptance of modern physics, we must realize the enormous impact quantum mechanics and wave-particle duality have upon a physicist's view of "reality." We pause briefly to examine the remarkable transformation from the physics of Newton to that of Heisenberg.

When Isaac Newton introduced his three laws of motion, he provided a structure within which we could understand all motion—from the falling apple to the orbiting planet. Once we knew all the forces acting on an object, we could predict all future motions with complete accuracy. By placing certainty squarely within the grasp of human intelligence, Newton created an enormously comforting view of our universe. This feeling of certainty was stated well by the French mathematician Pierre LaPlace:

An intelligence which at a given instant knew all the forces acting in nature and the position of every object in the universe—if endowed with a brain sufficiently vast to make all necessary calculations—could describe with a single formula the motions of the largest astronomical bodies and those of the smallest atoms. To such an intelligence, nothing would be uncertain; the future, like the past, would be an open book.

Newton's model created an image of a rational world proceeding in a rational way—a world view eagerly embraced by philosophers, theologians, and physicists alike.

Beneath this world view lie two very important assumptions. The first is that all events are ordered, not random. To Newton and his contemporaries, all motion was completely determined by whomever or whatever started the universe. These motions obeyed and would continue to obey a series of orderly rules that could be discovered by the careful observer. The second assumption was that the physicist acts as an objective observer of events. Newton and his contemporaries believed that while the measurer does have some impact on the events he or she measures, this impact is minimal and predictable. Events continue, according to a system of ordered rules, with an existence independent of the observer. All that remained was for science to discover the rules.

During the eighteenth and nineteenth centuries, when Newton's laws were

applied to objects as small as molecules, this world view prevailed. In principle, physicists believed, once they knew the momentum and position of each molecule, they could predict all future motions of all molecules. Completing these measurements and calculations for a gram of water, let alone the entirety of the universe, was not humanly possible, so statistical or probabilistic descriptions of nature were adopted. Consistent with Newton's world view, probabilities were needed only to compensate for an information overload, not because of the inherent unknowability of nature.

What does the new world view have to say to us about our knowledge? Implicit in the probabilistic interpretation now given to matter waves is the assumption that, on the microscopic level, events are random. Wave descriptions provide us information about the probabilities associated with this random behavior; particle measurements convert these probabilities into brief certainties. Further, objective observers have become active participants in the world that they are trying to describe. Physicists now acknowledge that the types of measurements they undertake affect the observations and models they subsequently construct. Words like *particle, position,* and *path* have no meaning apart from the way in which the experimenter measures them. These words describe our way of ordering the events we see, not a true underlying structure of nature. Newton's view of an orderly nature that exists independent of how we observe it exists no more.

For many physicists the radical departure from more traditional ideas was difficult to accept. Erwin Schrodinger, whose equations were the Newton's laws of quantum mechanics, remained uncomfortable with the probabilistic interpretation given to matter waves. Albert Einstein, whose quantum explanation of the photoelectric effect won a Nobel Prize, also remained unconvinced. He felt that quantum theory was only a stepping stone to a more complete understanding of matter. In this view, probabilities do not represent nature but rather, people's limited ability to comprehend nature. In a letter to Max Born in 1926, Einstein summarized his and perhaps many others' feelings:

Quantum theory is certainly imposing. But an inner voice tells me that it is not yet the real thing. The theory says a lot, but does not really bring us closer to the secrets of the "old one." I, at any rate, am convinced He is not playing at dice.

Only time will tell whether Einstein's inner voice was the voice of wisdom or the voice of a past, unwilling to give way to the future.