4. THE OBSERVER.

From the time of Isaac Newton to the beginning of the twentieth century science relegated consciousness to the role of passive viewer: our thoughts, ideas, and feelings were treated as impotent bystanders to a march of events controlled wholly by contact interactions between tiny mechanical elements. Conscious experiences, insofar as they had any influences at all on what happens in the world, were believed to be completely determined by the motions of miniscule entities, and the behaviors of these minute parts were assumed to be fixed by laws that acted exclusively at the microscopic level. Hence the *idea-like* and *felt* realities that make up our streams of conscious thoughts were regarded as redundant, and were denied fundamental status in basic theory of nature.

The revolutionary act of the founders of quantum mechanics was to bring conscious human experiences into the basic theory of physics in a fundamental way. In the words of Niels Bohr the key innovation was to recognize that "in the drama of existence we ourselves are both actors and spectators." [Bohr, Essays 1958/1962 on Atomic Physics and Human Knowledge]. After two hundred years of neglect, our thoughts were suddenly thrust into the limelight. This was an astonishing reversal of precedent because the enormous successes of the prior physics was due in large measure to the policy of keeping idea-like qualities out.

What sort of crises could have forced scientists to this wholesale revision of their idea of the role of mind in their description of Nature? The answer is the discovery and integration into physics of the "quantum of action." This property of matter was discovered and measured in 1900 by Max Planck, and its measured value is called "Planck's

Constant." It is one of three absolute numbers that are built into the fundamental fabric of the physical universe. The other two are the gravitational constant, which fixes the strength of the force that pulls every bit of matter in the universe toward every other bit, and the speed of light, which controls the response of every particle to this force, and to every other force. The integration into physics of each of these three basic quantities generated monumental shifts in our conception of nature.

Isaac Newton discovered the gravitational constant, which linked our understanding of celestial and terrestrial dynamics. It connected the motions of the planets and their moons to the trajectories of cannon balls here on earth, and to the rising and falling of the tides. Insofar as his laws are complete the *entire physical universe* is governed by mathematical equations that link every bit of matter to every other bit, and that moreover fix the complete course history for all times from conditions prevailing in the primordial past.

Einstein recognized that the "speed of light" is not just the rate of propagation of some special kind of wave-like disturbance, namely "light". It is rather a fundamental number that enters into the equations of motion of every kind of material substance, and that, among other things, prevents any piece of matter from traveling faster than this universal limiting value. Like Newton's gravitational constant it is a number that enters ubiquitously into the basic structure of Nature. But important as the effects of two quantities are, they are, in terms of profundity, like child's play compare to the consequences of Planck's discovery.

Planck's "quantum of action" revealed itself first in the study of light, or electromagnetic radiation. The radiant energy emerging from a tiny hole in a heated hollow container can be decomposed into its various frequency components. Classical nineteenth century physics gave a clean prediction about how that energy is should be distributed among the frequencies, but the empirical facts did not fit that theory. Eventually, Planck discovered that the correct formula could be obtained by assuming that the energy was concentrated in finite packets, with the amount of energy in each such unit being directly proportional to the frequency of the radiation that was carrying it. The ratio of energy to frequency is called "Planck's constant". Its value is extremely small on the scale of normal human activity, but becomes significant when we come to the behavior of the atomic particles and fields out of which our bodies and brains and all large physical objects are made.

It took twenty-five years for Planck's "quantum of action" to be integrated coherently into physics. During that interval from 1900 to 1925 many experiments were performed on atomic particles and it was repeatedly found that classical laws did not work. They gave well defined predictions that were contradicted by the empirical facts. But it was clear that that all of these departures of fact from theory were linked to Planck's constant.

Heisenberg finally discovered in 1925 the completely amazing and wholly unsuspected and unprecedented solution to the puzzle of the failure of the classical laws: the quantities that classical physical theory was based upon, and which were thought to be numbers, *are not numbers at all*. Ordinary numbers, such as 2 and 3, have the property that the product of any two of them does not depend on the order of the factors: 2 times 3 is the same as 3 times 2. But Heisenberg discovered that one could get the correct answers out of the old classical laws if one decreed that the *order in which one multiplies* certain quantities matters!

This "solution" may sound absurd or insane. But mathematicians had already discovered that completely coherent and logically consistent mathematical structures exists in which the order in which one multiplies quantities together matters. Ordinary numbers are just a very special case in which A times B happens to be the same as B times A. There is no logical reason why Nature should not exploit the more general case, and there is no compelling reason why our physical theories must be based exclusively on ordinary numbers. Quantum theory exploits the more general logical possibility.

An example may be helpful. In classical physics the center-point of each object has, at each instant, a well defined location, which can be specified by giving its three coordinates *(x, y, z)* relative to some coordinate system. For example, the location of a spider dangling in a room can be specified by letting *z* be its distance from the floor, and letting *x* and y be its distances from two intersecting walls. Similarly, the *velocity* of that dangling spider as drops to the floor, blown by gust of wind, can be specified by giving *the rate of change* of these three coordinates (x, y, z). If each of the three numbers that together specify the velocity are multiplied by the weight (=mass) of the spider, then one gets three numbers, say (p, q, r), that define the "momentum" of the spider.

Now in classical mechanics the symbols x and p described above both represent *numbers*: the symbol *x* represents the distance of the spider from the first wall, measured in some appropriate units, say inches; and the symbol p likewise represents some *number* connected to the velocity and weight of the spider. Because *x* and *p* both represent just ordinary *numbers*, the product x times p is the same as p times x, as we all learned in school. But Heisenberg's analysis showed that in order to make the formulas of classical physics describe quantum phenomena, x times p must be different from p times x. Moreover, he found that the difference between x times p and p times x must be Planck's constant. [Actually, the difference is Planck's constant multiplied by the imaginary unit *i,* which is a number such that *i* times *i* is minus one.] Thus quantum theory was born by recognizing, or declaring, that the symbols used in classical physical theory to represent ordinary numbers actually represented mathematical objects such that their ordering in a product was important. The procedure of creating the mathematical structure of quantum mechanics from classical physics by replacing the ordinary numbers by these more complex objects is called "quantization." That process is an essentially straightforward mathematical operation, but it needed to tied in some well-defined way to empirical data before becoming part of science. Establishing this link involves not just mathematics, in a narrow sense, but involves also philosophy, in a broad sense.

By the year 1900 scientists believed that they had certainly discovered the nature of the fabric of reality into which our experiences are woven. External physical reality was understood to be composed of moving atomic particles and changing physical fields. The classical laws governing the behavior of these physical realities had been proposed by Isaac Newton, James Clerk Maxwell, and Albert Einstein. What Heisenberg found out was that in order to accommodate phenomena in which the value of Planck's quantum of action is important the symbols, such as *x* and *p,* that appear in the earlier theory have to be replaced by mathematical objects such that their ordering in a series of factors matters. What this mathematical change does, *conceptually*, is to convert the conception of a particle as a minute entity into the conception of a "particle" as an extended cloud-like structure.

Physicists had, for more than two hundred years, imagined Nature to be composed, at least in part, out of entities resembling miniature planets. This idea of minute physical entities had become so deeply entrenched the psyches of scientists that it had acquired almost the status of an article of faith: if you do not belief it your not a scientist. But Nature, as she now reveals herself to us through our observations and our mathematics, appears to be made out of a very different kind of stuff. Careful analysis shows that atomic particles can never reveal themselves to be the tiny moving objects that they had been imagined to be since the time of Isaac Newton. Nor is there any reason to believe that such tiny objects exist at all. Each "particle", insofar as we can ever know it, may be associated with a particular mass (e.g., the mass of an electron) and a particular charge (e.g., the charge of the electron), but there is no evidence that it has a particular location. All the empirical evidence is most parsimoniously represented by taking each atomic particle to be a cloud-like structure that has a strong proclivity to spread out over ever-larger regions.

However, this diffusing tendency of the "clouds" does not proceed unchecked forever. There is a *counter process*, which consists of a sequence of "quantum jumps." These events are sudden collapses of the cloud. At one moment the form may extend over miles, but an instant later it is reduced to the size of a speck. Yet how can we make good scientific sense out of such a crazy idea of how the world behaves?

Einstein described a simple situation that illustrates the puzzling character of these quantum jumps. Suppose a radioactive atom is placed in a detecting device that responds to the decay of this atom by sending an electrical pulse to a recording instrument that draws a line on a moving scroll. A blip in this line will indicate the time at which the electrical signal arrives. Next, suppose some scientists are observing the instrument and reporting to each other where the blip is located on the scroll. What we know is that these observers will more or less agree amongst themselves as to the position of the blip. But quantum theory has stringent laws that govern in principle the behavior of all physical systems. If one applies these rules to the entire system under consideration here, which consists of the radioactive atom, the detecting device, the electrical pulse, the recording instrument, the bodies and brains of the human observers, and all other physical systems that interact with them, then one arrives at a contradiction. What we know is that the blip seen by the observers occurs at a fairly definite location. But according to the quantum laws the full physical system will be a smeared out continuum of possible worlds of the kind that occurred in classical physics. In each of these classical-type worlds the blip will occur at some particular location on the scroll, and all of the observers will be reporting to each other that they see the blip at that location. However, the full cloud-like quantum state will include, for each of the infinity of possible locations of the blip on the scroll, possible worlds in which the blip occurs at that location, and in which all of the observers report seeing the blip occurring at that particular location.

In short, the quantum law, or rule, that governs the behavior of matter generates a whole continuum of possible worlds of the kind that appear in our streams of conscious experiences. The world that you experience is just one tiny slice of the full world generated by the quantum laws obtained by incorporating the correct measured value of

Planck's constant into the otherwise incorrect laws of classical physics.

This mismatch, which lies at the central core of quantum theory, is a discord between the two distinct parts of science, the theoretical and the empirical: it is a disparity between theory and (experienced) fact. These two interrelated aspects of science are extremely different in character. Each *fact* comes as a chunk of somebody's experience. But these disjoint chunks are related to each other. At one moment you see a chair, then look away. Upon looking back you see a chair that resembles the one you saw before. You were alone in the room, hence no continuous human experience bridges the gap between these experiential moments. Yet the two experiences are obviously linked together by something.

How do we human beings, scientist and nonscientist alike, deal with the manifest linkages between the disconnected perceptual facts? The answer is this: we concoct *theories*! We create ideas about persisting realities that exist even when no one is watching them, and that bind the disjoint facts together. Our physical theories are conceptual frameworks that we create for the purpose not only of organizing our perceptual experiences, but also of permitting us even to have understandable and describable experiences. We need at least a rudimentary "theory of reality" even to grasp and describe the idea that some piece of apparatus has been placed in a certain location and is, itself, behaving in a certain way. As Niels Bohr succinctly puts it: "The task of science is both to extend the range of our experience and reduce it to order." [N. Bohr. Atomic Physics and Human knowledge, p.1].

The unique quantum laws produced by the quantization procedure make predictions about empirical data that are accurate to as much as one part in a hundred million, and they correctly describe various features of the behavior of systems of billions of particles. But Einstein's example shows that these quantum laws of motion lead also to cloud-like physical states that are grossly discordant with the more narrowly defined character of our actual experiences.

You might think that this huge conflict between the mathematical theory and the empirical facts would render the theory false and useless. But the amazing thing is that the creators of quantum theory found that *all of the successes of classical physics* and a great deal more could be explained, without any contradiction ever arising, by adopting the following dictum: assume that the quantum generalization of the old classical laws do indeed hold, but if they lead to a physical state that disagrees with your empirical observation then simply discard the part of that (mathematically computed) state that disagrees with your observations, and keep the rest. This sudden resetting of the physical state is the "quantum jump." By itself it would yield nothing. But it is accompanied by a natural statistical law, which will be described later, that produces all of the wondrous results just described.

How can a theory of this kind make sense? Well, notice that you, yourself, like all of us, are continually creating, on the basis of the best information and ideas available to you a theoretical image of the physical world around you: you have an idea about the status of all sorts of things that you are not currently experiencing. Each time you gain information you revise that theoretical picture to fit the newly experienced facts.

Quantum theory instructs the scientist to do the same. That simple dictum (revise your theoretical picture of the world to fit the empirical facts), together with its statistical partner, produces not only incredibly accurate predictions, but every successful result of the earlier classical physics, and all of the thousands of successes of quantum theory where classical physics fails. These impressive results are achieved by simply allowing the beautiful, internally consistent, and unique quantized version of the old classical laws to hold whenever we are not actually acquiring knowledge about a physical system, but incorporating promptly any knowledge we acquire. The close connection maintained in this way between what the mathematical description represents and what we empirically know underlies Heisenberg's assertion that the quantum mathematics ``represents no longer the behavior of particles but rather our knowledge of this behavior.''

The shocker, however, is that Bohr and the other founders have argued persuasively that *no other description of nature in terms of its atomic constituents can be more complete than this one,* in the scientific sense of telling us more about relationships between human experiences. That is, this theory, constructed by incorporating the measured value of Planck's constant into the old and incorrect classical laws, appears to tell us everything that a basic physical theory could ever tell us about connections between empirical facts.

This claim of scientific completeness, made by Heisenberg, Bohr, and the other founders of quantum theory, was disputed by Einstein, who tried repeatedly to devise a counter-example. But the quantum theorists shot down every try. Thus it does indeed seem to be true that this fantastically coherent quantization of the older laws generates *everything that is knowable about reality*: this quantum description of nature, crazy jumps and all, appears to be, from a narrow scientific point of view, our best picture of nature. Any attempt to add something more may please some philosophers, but carries us outside of science, regarded simply as a tool for "expanding our experience and reducing it to order."

This apparent scientific completeness of quantum theory, together with the fact that the "quantization" procedure totally *eliminates* the classically conceived tiny entities, and replaces them by cloud-like forms, make plausible the conclusion that there simply are no *classical-type or quasi-classical-type* realities lying behind our thoughts, and that searching for them is a futile endeavor. The presumption that such realities exist is therefore a gross philosophical blunder. There is absolutely no empirical evidence that rationally supports the notion that there is a physical reality out there that is better defined than what quantum theory allows. The assumption that such a quasi-classical type reality exists is not justified by the scientific evidence, and is thus likely to produce a conception of both nature and human beings that is fundamentally incorrect.

But let us be clear about one thing: although quantum theory is an endeavor to rationally order the empirical facts, and is therefore erected upon human experience, it does not assert that our thoughts are the *only* realities, and matter naught but an invention of the mind. The founders did not espouse the philosophy of idealism. (Everything is made out of ideas alone: "To be is to be perceived.") Their position was the more conservative one that science is about what we can know, and that a physical theory must be judged not by concordance with intuition, but rather by its rational coherence, its capacity to accommodate the known facts, and its power to make reliable predictions about future experiences. This view liberates theoretical creativity: it allows science, unfettered by ancient prejudice and fallible intuition, to construct a practically useful and *empirically based new idea of the nature of reality.*

Revamping the physics and the philosophy in this radical way did not satisfy everyone, Einstein and Schroedinger being the most notable hold-outs. But it did allow the scientists who accepted it to get on with the business of developing, testing, and using this immensely successful theory.

I have stressed that the founders of quantum theory brought human consciousness into basic theory of nature. But the really essential point is that your mental life inserted in two distinctly different ways. The first is as a passive stream of conscious thoughts that constitutes a growing reservoir of knowledge: each waking moment adds something new to what you knew before. The second is as an active agent endowed with a free will that can influence both how your body moves and how your thoughts unfold. Explaining and exploring that active aspect is the purpose of this book. But to understand yourself as participant you must also appreciate yourself as the intertwined expanding collection of knowings upon which your actions are based.

As might be expected, this radical restructuring of physics is not achieved without some rearrangements of old ideas. For example, "The Observer" as understood in the original "Copenhagen" formulation of quantum theory differs from what one would normally mean by this term. In particular, it involves an extension of the human observer outside his physical body. Bohr mentioned several times the example of a man with a cane: if he holds the cane loosely he feels himself to extend only to his hand. But if he holds the cane firmly then the outer world seems to begin at the tip of his probing cane.

In analogy, "The Quantum Observer" is considered to include not only the body and mind of the experimenter himself, but also the measuring devices that he uses to probe what is outside that extended "self". Thus the world is imagined to be cleaved into two parts, which are described in different ways. The outer "observed system" is described in terms of the quantum mathematics, whereas the inner "observing system" is described as a collection of empirical (i.e., phenomenal or experiential) facts. This way of dividing the world implements the point, stressed already above, that quantum physics --- like all of science --- rests on two disparate kinds of descriptions, the first being of conscious experiences that we can record, remember, and communicate to our colleagues, and which form the empirical database, and the second being of a theoretical structure that we have invented for the purpose of comprehending the structure of our experience.

Copenhagen quantum theory regards the measuring instruments as part of the observer because these devices are described not in terms of their atomic constituents but rather in terms of our conscious knowings. Bohr repeatedly points to this key feature of quantum theory, in statements such as:

"The decisive point is that the description of the experimental arrangement and the recording of the observations must be given in plain language, suitably refined by the usual terminology. This is a simple logical demand, since by the word `experiment' we can only mean a procedure regarding which we are able to communicate to others what we have done and what we have learnt." (Essays 1958/1962….p.3)

I have described here the basic ideas of the Copenhagen approach to physics, and explained its essential reliance upon the experiences of the observers. This philosophical framework is conceptual container for a rigid mathematical structure, and this receptacle, or mold, was shaped in large part by the rigid form that it was designed to hold. That uncompromising structure, which was generated by incorporating Planck's quantum of action into the old pre-quantum laws of physics, captures and reveals aspects of nature that supercede and negate all the scientific ideas about the fundamental nature of reality that existed at the dawn of the twentieth century. So having now described the philosophical environment that was created to cradle the new mathematics, and to connect it to empirical data, we are in a good position to see what that new mathematical structure is like. The ideas are basically simple, once old prejudices and obscuring jargon are stripped away. With the correct tools then in hand, we shall be able to describe the mathematical rules that allow your thoughts, feelings, and efforts to influence your mental and physical behavior.

5. THE UNSEEN.

Quantum theory represents our knowledge about the unseen system being probed by means of a mathematical structure called the quantum state. This state normally evolves continuously in accordance with a deterministic law that is closely connected to the "laws of nature" used in classical physics. However, at certain instants this orderly progression is suddenly interrupted by an abrupt "quantum jump". Such a jump occurs each time one of the observers gains new knowledge: the jump brings the quantum state into concordance with the new state of our knowledge. Thus the quantum state of the system being examined represents always the evolving knowledge of the community of communicating observers.

But how can a mathematically described state represent human knowledge?. Our knowledge seems to be an ephemeral and ineffable vagary, whereas the mathematically described states of quantum theory are precise structures that allow empirically observed numbers to be computed to an accuracy of one part in a hundred million.

To explain this connection I need to introduce two mathematical ideas: "Hilbert space", and "projection operator". These names may sound intimidating, but the ideas are basically simple, and understanding them will allow you to grasp the essence of quantum theory.

A Hilbert space is a collection of *vectors*, and a vector is a displacement by a specified amount in a specified direction. Two vectors, A and B, can be added together to give a vector C, which is formed by adding together the displacements A and B.

Consider, for example, the displacement from the corner of a room where two walls and the floor meet to a point on one of these two walls. That displacement is the sum of a vertical displacement up from the corner plus a horizontal displacement along the wall that contains the point.

If the two vectors A and B that add to give C are perpendicular to each other, as in this example, then the theorem of Pythagoras asserts that the square of the length of A plus the square of the length of B equals the square of the length of C.

This celebrated theorem is tied to the probability rules of quantum theory: If C is a vector of length one (i.e., unity) and A and B are two perpendicular vectors that sum to C, then the square of the length of A plus the square of the length of B is unity (i.e., one). The two perpendicular vectors will correspond to two *alternative possible outcomes of a probing action*, and the square of the length of A will be the probability for the event associated with A to occur, and the square of the length of B will be the probability for the event associated with B to occur. The sum of these two probabilities is unity by virtue of the theorem. This accords with the fact that the probabilities associated with alternative possibilities must sum to unity.

In the example of the point on the wall, the space of vectors is two-dimensional: any point on the wall can be reached from the corner by a sum of just two displacements, one in each of the two pre-specified perpendicular directions, vertical and horizontal. We can also easily visualize displacements in a three-dimensional space. But it is possible to consider mathematically an N-dimensional vector space in which there are exactly N mutually perpendicular directions, and each vector in the space is a sum of N vectors, one directed along each of these N directions. We allow null displacements and also negative displacements, which are the same as positive displacements in the reverse direction.

A set of N vectors, each perpendicular to every other one, is not easy to visualize, geometrically, for large N. But if one uses an algebraic approach in terms of sets of numbers, then the examples of vector spaces in one, two, and three dimensions are easily generalized to spaces of arbitrarily large but finite dimension N. With a little more effort one can even go to the case where N is infinite. Hilbert spaces include the infinite-N cases, but that is a technical matter that need not concern us here. It will be enough to think of simple cases where N in finite.

If a vector V is composed of a sum of N perpendicular vectors then a generalization of the theorem of Pythagoras shows that the square of the length of V is the sum of the squares of the lengths of these N mutually perpendicular vectors that add up to form V.

The second important concept is the idea of a projection operator. A *projection operator* P acts on a vector V to give a new vector PV. The action of P eliminates a specified subset of a set of perpendicular vectors that add up to give the vector V upon which it acts, but leaves unaffected the remaining vectors in the sum. Thus, for example, the vector V from the corner of a room to any point in the interior of the room would be converted by a certain projection operator P to the vector PV that is the displacement from the corner to the point on the floor that lies directly under that point in the room: the vertical vector is eliminated by the action of this particular projection operator P.

That example is a very special case. For one thing the three perpendicular vectors were very special, involving one vertical vector and two particular horizontal ones. But one can imagine replacing the room by a cubic box, and consider the infinity of ways that this box could be oriented relative to the room. For each of these orientations the three edges that meet at a corner define three perpendicular directions. Then one can go from N = 3 to arbitrary N, and select any subset of the set of N perpendicular directions to be the set that is not set to zero. This obviously gives a huge set of logically possible projection operators P.

For each projection operator P there is a unique complementary projection operator P' that does *not* set to zero exactly the subset of the N perpendicular vectors that *is* set to zero by P. Thus for any vector V, it is true that PV + P'V = V. The vectors PV and P'V are two perpendicular vectors that sum to V.

Given this simple idea of a vector, and how a vector in an N dimensional space can be considered to be a sum of a set of N vectors, each of which is perpendicular to every other one, we can now state the basic idea of quantum theory: Our knowledge about the unseen system, gleaned from earlier experience about things we *can* see, is represented, under certain ideal conditions, by a vector V of unit length. This vector evolves under the action of a rule called "the Schroedinger equation", which alters the direction that V points, but leaves its length unchanged.

When the outcome of a probing action appears the vector V suddenly jumps to the vector PV or to P'V, where P is the projection operator associated with the probing action, and P' is the complementary projection operator. The probability of V jumping to PV is the square of the length of PV and the probability that the jump will be to P'V is the square of the length of P'V. These two probabilities add to unity, by virtue of the theorem of Pythagoras. This property matches the property of probabilities that their sum over any set of alternative possibilities must be unity.

The essential point here is that our knowledge of the unseen system being probed can, according to quantum theory, be associated with a vector V in a Hilbert space, and this association gives simple rules for the probabilities for the alternative possible outcomes of our probing action to appear, once the form of the projection operator P is known.

With this general picture in mind we can now return to the question of how our knowledge is represented mathematically.

According to quantum theory the polarization of a photon is represented by a vector V in the two dimensional space that is perpendicular to the photon's line of flight. Suppose a photon is allowed to fall on a crystal that splits the beam so that the part polarized along direction A1 is deflected to a photon detector D1 and the part polarized in the direction A2, perpendicular to A1, is deflected to a photon detector D2. If the detectors are 100% efficient then one or the other of the two detectors will fire, but not both.

In this example the probing action is associated with the projection operator P such that the vector PV is directed along A1 and P'V is directed along A2. The vectors PV and P'V represent the *alternative* possible outcomes of the probing action. If the observer sees detector D1 fire that he knows that the system being probed is in state PV; if he sees detector D2 fire then he knows that the system being probed is in the state P'V. Thus quite accurate information about the new state of the unseen system can be gleaned from the empirically discernible fact of whether D1 fires or D2. Discarding the part of the state V=PV +P'V that is incompatible with the empirical fact that D1 fires and D2 does not, or vice versa, is non problematic.

The successive action upon a vector V, first of the projection operator P1 and then of the projection operator P2 is represented by V'=P2 P1 V. In general this vector is different from V"=P1 P2 V: the order of in which the two operators P1 and P2 appear matters! This can be easily verified in simple cases, and is not mysterious. All dependences of products on the ordering of the factors in quantum theory can be traced to this completely understandable dependence.

I specified at the beginning that V represented of *our knowledge* of the system being probed. Thus there is no problem with the fact that V suddenly changes when an observer acquires new knowledge by seeing one of the two the detectors, D1 or D2, fire and the other one not fire. However, this facile way of speaking glosses over some deep problems. This vector V seems to be connected more closely to the state of the photon itself than to human consciousness. The very fact that the photon could be represented by a vector, and that this vector should evolve normally in accordance with the Schroedinger equation was a consequence of incorporating Planck's constant into the equations of classical physics. That quantization procedure converted the old classical-type of reality into the new cloud-like (or vector-type) replacement. This transformation seems to be an objective change, not related specifically to human consciousness. Moreover, the stability of matter itself, and the formation of the elements, are all understood in terms of these quantum equations of motion. All of this structure and process predates human existence. The original Copenhagen pragmatic way of understanding the quantum mathematics, while tremendously useful as a stepping stone, closes the door to any real understanding of the reality that replaces the one that empirical phenomena has ruled out.

6. THE PARTICIPANT

Niels Bohr, the principal architect of quantum philosophy, wrote that we cannot forget "that in the drama of existence we ourselves are both actors and spectators." [Essays 1958/62 on Atomic Physics and Human knowledge, p.15] This comment succinctly captures a key point of quantum theory: the human observers are no longer passive witnesses to a flow of physical events that they cannot influence. They are essential players in the action: their "free" choices can influence the flow of physical events.

Quantum theory, in spite of its idealistic content, is formulated in a completely realistic and practical way. It is structured around the activities of human agents, who can probe nature in any of many possible ways. Bohr emphasized this freedom of the experimenters in passages such as:

"The freedom of experimentation, presupposed in classical physics, is of course retained and corresponds to the free choice of experimental arrangement for which the mathematical structure of the quantum mechanical formalism offers the appropriate latitude."

The point here is that quantum theory, in its original form, is set up in terms of an interaction between conscious human agents and an invisible quantum system. As already discussed, that system is represented in the theory by a vector in Hilbert space. This vector usually evolves according to the quantum law of motion, the Schroedinger equation. But to get information about that system the experimenter must ask specific questions by setting up corresponding probes. For example, the experimenter can orient the crystal in the photon experiment described earlier in any way he chooses. Different choices correspond to different choices of the two perpendicular directions A1 and

A2. Moreover, the human agent can choose to do or not do the experiment, or to do it sooner or later. These choices are, according to our basic physical theory, quantum theory, not fixed by any yet-known laws of nature. Hence these choices are, in that specific sense, "free choices".

We have now arrived at the crux of the matter! Quantum theory, in its orthodox formulation, involves the human observer not merely as a passive recipient of data, but also as an active agent that enters into natural process in ways that are not controlled by the known physical laws. His specific role, *as it appears in the world of experience*, is to select which experiment is to be performed: i.e., to choose which aspect of nature will be probed. This role, *as it appears in the mathematics*, is to select some one single projection operator P. This P is the projection operator such that the initial vector V will become PV if nature delivers the affirmative answer 'yes' to the posed question, but will become the vector P'V if nature delivers the negative answer 'no'. Here P' is the projection operator that keeps the vectors that P eliminates, and hence satisfies the condition PV+P`V=V for all V.

[Sometimes a complex question involving a combination of several projection operators can be considered. But these can be regarded as a sequence of individual P's, and I shall adopt this simpler way of speaking.]

The essential point here is that, according to orthodox ideas, nature's process of generating the experiences that appear in our streams of consciousness cannot proceed without particular questions being posed. But then the two key questions become:

If the known physical laws do not determine the choices that need to be made by the human agents in order for nature's process of generating human experiences to proceed, then what sort of considerations do influence or determine these choices?

and

What effect do these "free" choices have on the course of physical events?

The evolution of the unseen system involves a sequence of questions with Yes or No answers. Hence the interaction between nature and agent is like a game of twenty-questions: the agent is free to choose a sequence of Yes-No questions, and nature delivers an answer, Yes or No, to each, in the form of an experience that answers the posed question. The choice of question is represented within the mathematical description as the selection of one projection operator P from among an infinite continuum of possibilities. Each possible P corresponds to *particular* way of orienting a set of N mutually perpendicular vectors, and, then, a *particular* choice of which of these N vectors will be eliminated to form PV. The process of making these *particular choices* of P's is not specified by the Schroedinger equation, which controls the *continuous* evolution of the physical state between observations, but neither the agent's choices of the questions nor nature's choices of the answer. In particular, a complete account of the dynamics needs to explain an as-yet-unexplained process that picks a sequence of particular P's from a continuum of possibilities. This selection process is associated, according to orthodox quantum theory, with consciously made free choices on the part of human beings. And, according to the quantum rules themselves, these "free choices" can influence the course of physical events, as we shall presently see.