Chapter 2
Waves, Particles, and Minds

Particles and Waves

Classical mechanics developed during the nineteenth century—due principally to the work of James Clerk Maxwell—into a form that involved two different kinds of physical stuff: "particles" and "waves". Electrons are the prime example of particles, whereas "light", in the form of the electromagnetic field, is the prime example of a wave. Particles are tiny, highly-localized structures, each with a center that, at each instant of time, is situated at one precise point in three-dimensional space, with the rest of the particle lying nearby. A wave, on the other hand, tends to spread out over a large region in space, and to exhibit "interference patterns" due to the cancellations or reinforcements of moving crests and troughs.

Particles and waves have, therefore, contradictory structures: particles always stay tiny, whereas waves tend to spread out. Thus Planck's discovery in 1900 that light, which had seemed to be a wave, had a corpuscular nature came as quite a shock. Light of a given frequency appeared to be emitted in chunks, each carrying a quantity of energy that is directly proportional to the frequency of the light wave, with a universal proportionality factor called Planck's constant. Albert Einstein won the Nobel Prize for his explanation, five years later, of the photo-electric effect. Empirically, a metallic surface radiated by light of a definite frequency emits electrons with energies equal—after a correction for the energy needed to get the electron out of the metal—to the energy of the incoming quantum of light, now understood to be localized like a particle.

The concepts of classical physics were unable to cope either with this wave-particle-duality problem, or with a large number of other problems concerning the properties of atoms. A new way of understanding nature was needed, and was created.

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Science and Philosophy

These problems of wave-particle duality and atomic structure appear to be completely physical in character. But the founders of quantum mechanics were men of profound philosophical bent. Niels Bohr's father was an eminent physiologist familiar with the writings of William James, and Wolfgang Pauli was the godson of the philosopher Ernst Mach. Werner Heisenberg, whose father was also a professor, was greatly influenced by the views of Bohr and Pauli. All three were strongly influenced by the view of Albert Einstein that science rests in the end on empirical findings, and that our physical theories are basically human inventions that help us deal with the world known to us only via our conscious observations and experiences. Bohr, concurring, announced at the start of his 1934 book, *Atomic Theory and the Description of Nature,* that "In physics…our problem consists in the coordination of our experiences of the external world." A few pages later (p. 18) he writes:

> In our description of nature the purpose is not to disclose the real essence of phenomena, but only to track down as far as possible relations between the multifold aspects of our experience.

In line with this viewpoint, the founders of quantum theory officially presented their theory not as what would normally be called a description of an existing and evolving material reality, as was done in classical mechanics. Their theory was offered, rather, as a tool that scientists have invented for making testable and useful predictions about future experiences on the basis of knowledge gleaned from prior experiences.

That official position was a secure one from which Bohr could defend the theory against Einstein's objections. It was useful also for keeping students on a productive track of learning how to use the theory in practical applications, and preventing them from spending (wasting?) their time pondering philosophical issues about which even the founders did not fully agree. Heisenberg and Pauli both devoted much time and effort trying to understand the nature of the reality lying behind the pragmatic rules. And von Neumann speaks in his discussion of the measuring process about the connection of the "intellectual inner life of the individual" to the circumstances "which actually exist in nature." He seems very clearly to be talking about an underlying reality, not merely a pragmatic tool.

The fate of classical mechanics provides a stark warning of the danger of taking initial success as tantamount to victory in the search for truth. Accordingly, the impressive empirical successes of standard (Copenhagen-Orthodox) quantum mechanics have failed to convince all physicists of the real need to bring into the dynamical laws any experiential quality that is not fully specified by the material and space-time structure of the universe. Alternatives to standard quantum mechanics have thus been proposed that are essentially in line with the precepts of materialism, which exclude from the dynamics all immaterial elements. But the theme of this book is that von Neumann's (orthodox) formulation of quantum mechanics, as elucidated herein, has, by virtue of the rational coherence of its mathematical, empirical, and philosophical components, the qualifications that warrant its being regarded as an adequate putative theory of reality itself. A "sine qua non" of an 'adequate' theory of reality is that it provide a rationally coherent understanding of the relationship between our conscious experiences and the associated processes occurring in our brains.

The Realistically Interpreted Orthodox Quantum Mechanics described here violates the demand of materialism that our conscious experiences have no causal power beyond what can be explained by the causal properties of matter alone—where 'matter' consists of things described in geometrical terms, and built out of geometrical structures like Newtonian particles and their associated energy-carrying fields.

This quantum mechanical world is basically a *psycho-physical* structure in which the causal effects of the disparate mental and atomic-particle-based elements are woven together by means of von Neumann's carefully formulated quantum dynamical laws. Those laws entail that a person's material actions can be influenced in specified ways by *his or her mental aspects in ways that are not fixed by the evolving material aspects of the universe alone. This understanding of standard (Copenhagen-Von Neumann) quantum mechanics is thus fundamentally non-materialistic: our mental aspects enter into the evolution of matter in ways not reducible to effects of matter alone. It is an understanding that is based on the words and concepts of the founders—particularly Heisenberg's and Bohr's reference to the "free choices" of probing actions on the part of experimenter-observers, and Dirac's choice of response on the part of "nature", all rigorously expressed in the mathematics and words of John von Neumann.*

This insertion of fundamentally mental causes into our basic physical theory generates a gross violation of what had, for two hundred years, been widely regarded as a key feature of a 'scientific' theory of reality; a feature considered to identify a proposed theory as science, as opposed to non-science. Indeed, the materialist demand of strict exclusion from the material world of all effects of mental causes is still regarded as a scientific imperative by many researchers, who consequently endeavor to explain the seemingly mind-related behavior of a person's body, whilst stoutly denying the possibility of any actual causal effect of that person's mind upon his or her bodily behavior.

But how did this radical break with materialism ever come about? How and why did the band of highly reputable physicists that created quantum mechanics suddenly, in 1925, feel entitled to make this huge break with the then-highly-honored classical materialistic tradition? The answer is to be found in:

Heisenberg's Seminal 1925 Discovery

The common idea of quantum mechanics in the minds of many non-physicists centers on Bohr's renowned model of the atom. According to that model, atoms are like miniature classical solar systems in which the circling electrons tend to stay on favored orbits, but make occasional "jumps" from one such orbit to another, with an associated emission or absorption of a photon. That model is an essentially classical physical system, with some added "quantum" conditions that there exist these favored orbits whose locations are related to the mysterious quantum constant discovered in 1900 by Max Planck.

Bohr's model dates from 1913, and hence was twelve years shy of the 1925 creation of quantum mechanics. While that 1913 model certainly does bring an important quantum element into the dynamics, it is seriously deficient as a characterization of the essential difference between classical mechanics and its quantum successor. It is ironic that this Bohr model of orbiting electrons is often offered as an example of the quantum nature of things, when, actually, the creation of quantum mechanics, triggered by Heisenberg's 1925 work, was precisely a rejection of the ideas of the 1913 quasi-classical Bohr model, with its definite trajectories of orbiting electrons, and lack of all reference to "our knowledge".

The key differences between standard Copenhagen/Orthodox quantum mechanics and its classical predecessor are, first, that the classical notion of particles as tiny objects moving on trajectories is replaced by the quantum notion of atomic particles represented by waves; second, that in the new theory these particles do not have well-defined trajectories; and third, that the needed abrupt collapses of the quantum states of systems are instigated by mental aspects of nature, not by purely mechanical/material aspect of nature acting alone. Thus our conscious experiences are, according to the new orthodox view, not causally inert bystanders, as in classical mechanics, but play an essential causal role in the determination of the objective psycho-physical future. These differences underscore the radically new ideas that emerged from Heisenberg's 1925 discovery, and that are mathematically embodied in realistically construed standard (Copenhagen/Orthodox/RQFT) quantum mechanics.

The principle of the "causal closure of physical" is, as mentioned earlier, sometimes regarded as part of a definition of science: a discriminating property that sets science apart from non-science. But science is perhaps better characterized, following the leads of Galileo and Bacon, by our essential use of probing actions intended to test hypotheses, and thereby allow us acquire knowledge about the material world; coupled with our practical applications of the knowledge that we thereby acquire.

Bohr's 1913 model does not bring into the dynamics any clear indication of a failure of the core precepts of materialistic classical physics. It merely adds some quantum conditions. And that model seemed to be putting physics onto a promising track. But then how and why did this radical triad of ideas (the representation of an atomic particle by a wave; the omission of particle trajectories; and the essential incorporation into the dynamics of the non-materialistic process of our acquiring knowledge) suddenly become accepted in 1925 by the founders of quantum mechanics as core precepts of their new physical theory? How did those completely alien and subversive ideas gain traction in a scientific environment so intrinsically hostile to it?

This abrupt 1925 turnabout was instigated by the persisting failures of the semi-classical attempts to account for the accumulating data of atomic physics, coupled with a profound discovery made in 1925 by Werner Heisenberg. He had come to believe that something was profoundly wrong with the (essentially classical) ideas of the 1913 Bohr model, and that the needed new theory should be built on properties that are actually known to exist—by virtue of our capacity to become cognizant of their numerical values by performing appropriate measuring procedures. These considerations directed Heisenberg's attention to the empirical processes of acquiring knowledge. While studying, theoretically, the processes of measuring, respectively, the 'location' and the 'momentum' of an atomic particle, say an electron, Heisenberg found that if the 'location' was measured first, and the 'momentum' second, then the product of the two outcomes differs from the product obtained when the two properties are measured in the reverse order. And the difference between these two products is essentially the famous constant that Planck discovered in 1900. Consequently, this completely unexpected connection between the outcomes of the two observation procedures must be connected to the quantum character of reality. And it entails that the process of acquiring knowledge about material properties cannot generally leave those properties undisturbed! For, if the process of acquiring knowledge allowed the observer simply to become aware of fixed pre-existing values then the two products of the outcomes could not remain differing by the fixed Planck's constant *in the limit in which the times of the two measurements tend to become equal. Heisenberg discovered that our actions of acquiring knowledge must disturb the observed system* in detailed ways *that are intricately tied to Planck's constant!*

That discovery quickly led Heisenberg, Born, and Jordan to a radically new theory based on the idea that, in keeping with certain prevailing philosophical ideas, the core subject matter of a satisfactory theory of the nature of things should be 'the evolving structure of our empirical knowledge of the world'—not 'the evolving structure of an imagined material world built primarily upon Newton's "solid, massy, hard, impenetrable, moveable particles'. Those particles can reasonably be viewed as pure fictions that happen to be useful in certain macroscopic contexts, but that fail to work in situations involving our acquiring of knowledge about the structure and behavior of atomic particles, particularly those contained in the neural/brain correlates of our perceptions.

The notion that the material world is built (principally) out of these Newtonian particles is, from the standard view of QM, a useful fictional creation of Isaac Newton. There exists no empirical evidence for their actual existence. Accordingly, the core subject matter of the new theory is taken to be something we do know, namely the structure of our evolving knowledge of the material world. This knowledge is asserted to be generated by the specified "objective mind-brain process of acquiring subjective knowledge". This process of observation is, according to the new theory, instigated in part—just as we innately feel it is—by the observer's mental intent and conscious effort, which thereby causally affect the observed material world. Orthodox QM spells out in great—although not complete–detail of how this mind-brain connection works.

Using measuring devices to acquire knowledge about matter dates from antiquity. And telescopes and microscopes were important in the development of classical mechanics. But in quantum mechanics Heisenberg's discovery entails that, in principle, these two processes of measurement—of 'location' and 'momentum'—cannot individually always leave the measured system just as it was, and with definite values of these two properties. For, if they did, then the product of the outcomes of these two knowledge-acquiring operations would have to be independent of the temporal ordering of these two procedures, in the limit in which they became simultaneous.

Thus Heisenberg's 1925 discovery entails that the increases in our knowledge of the properties of matter, which we acquire by performing measurements, cannot in general leave the state of the measured matter unchanged, and with definite values of these two properties. The probing processes that allow us to gain knowledge about properties of matter must 'in principle' sometimes 'disturb' those properties by finite (non-zero) amounts specified by Planck's constant. But in classical mechanics this difference can in principle be smaller than what quantum reality demands! Thus, in order to accommodate Heisenberg's finding, about the mind-brain connection we must, as a matter of principle, abandon classical mechanics, and, more generally, the philosophy of materialism!

The problem facing the founders was not merely to acknowledge the failure of the simple idea that we trivially acquire knowledge of the material world by simply mentally grasping directly the material facts, as was effectively assumed in classical mechanics. It is obvious that the fact that we can learn about the motions of the tiny pinpoints of light that correspond to planets, without appreciably affecting their motions, does not automatically carry over to the motions of the points that correspond to the locations of the electrons or atoms in our brains. The needed quantum theory had to account for the fact that the process of acquiring knowledge about the properties of the material world had to disturb the material structure in precisely the quantitative way needed to account for Heisenberg's findings! Thus a major revision in our understanding of the mind-matter connection lies at the heart of quantum mechanics.

To expect, under these conditions, to understand the mind-brain connection within the materialistic classical framework is truly an "Astonishing Hypothesis"—as was recognized by Francis Crick, who nevertheless espoused it, and called for a classical-physics-based neuroscience. That recommendation has dominated subsequent neuroscience, and produced a plethora of data, but, unsurprisingly, no understanding of how our mental consciousness is connected to our material brains. This book is about the non-astonishing orthodox QM claim that the mind-matter connection is a quantum effect.

In the light of Heisenberg's discovery, the founders of quantum mechanics were emboldened to let go of classical mechanics, which effectively sets Plank's constant to zero, in conflict with nature, and, instead, build a rationally coherent alternative to classical mechanics that incorporates into its foundational structure Heisenberg's discovery pertaining to the general non-trivial effects of the process of acquiring subjective knowledge about the objective state of the material world, and that moreover permits precise predictions about the observed structure of human knowledge. Within this quantum framework a person's acquired knowledge of material properties is not a faithful representation of the pre-probing properties of the observed system, but is, instead, an output of a dynamical probing processes initiated by the observing person. The observer's un-coerced-by-matter choices of what to observe affect the temporal evolution of the material aspects of nature.

One therefore cannot exclude the effects of the processes of our acquiring knowledge from of an adequate basic physical theory. That effect is both limiting and liberating: it limits, via the uncertainty principle, what we can know, but expands, via the entailed power of our minds, the possibilities for what we can do!

The orthodox quantum framework is, therefore, not just an arbitrary construct conjured up out of thin air by the founders, *and justified merely by its eventual success in accounting for the behavior of matter*. The driving endeavor of the founders was to create a rationally coherent conceptual structure that accommodates and explains—and is able to make useful predictions about—the structure of our conscious experiences. Our experiences thereby become the basic veridical realities of the theory, not misleading delusions.

Heisenberg's 1925 discovery was that the process of acquiring knowledge about the material world is very nontrivial! It is not a mere grasping of preexisting realities, but a highly structured action upon those realities. That unexpected result elevates the science-based conception of ourselves from passive observers to active agents. That reversal is the underlying core message of quantum mechanics! In the oft-cited words of Niels Bohr: "In the drama of existence we are ourselves both actors and spectators."

Standard quantum theory is thus a psycho-physical (or perhaps an episto-material) theory of the interaction of the evolving material aspects of nature with our evolving knowledge of those aspects. The theory, with its detailed agreements with observed (hence macroscopic) data, emerged, basically, from Heisenberg's guiding principle, which restricts what the theory 'postulates to exist" to properties of a kind that we can, via our observations, 'know exist'. His principle was to build on an empirically secure foundation, instead of empirically unsupported guesses.

The close agreement of the resulting theory with the normal objective empirical data is certainly a bottom-line success. But standard quantum theory describes, via Process 1, also the dynamical connection between a person's mentally instigated actions and that person's consequent mental perceptions of material responses to those actions, Any putative alternative "non-standard quantum theory" that fails to provide a rational theory of these more subjective aspects of the mind/brain connection is fundamentally deficient, compared to the standard quantum mechanics.

It was the assumed possibility for an ideal observer to know in principle, simultaneously, both the 'location' and the 'momentum' of every particle in the universe (and eventually the analogous properties of the fields) that allowed Laplace to deduce from the materialist principles of classical mechanics the "determinism" of the material world, and hence, within the framework of classical mechanics, the impossibility of a causal intervention of anything not fully characterized by its material properties. But that whole notion of the "causal closure of the physical" fails in a world where the mind-dependent quantum dynamical rules prevail.

We do not directly perceive atomic particles. We perceive only 'big' (macroscopic) systems that are built out of combinations of large numbers of atomic particles (and their associated physical fields). Quantum mechanics has well-defined rules for combining many atomic particles together to make big objects and systems, and to represent in mathematical language the purely mechanical (Process-2) aspect of the evolution of those macroscopic systems.

A 'big' physical object, although perceived in classically describable terms, is not causally governed by the laws of classical physics. It must be treated as a conglomeration of its atomic (quantum) constituents in order to account for its physical properties such as rigidity and electrical conductivity. Yet if it is treated as a conglomeration of its atomic quantum mechanical constituents evolving in accordance with Process 2 alone, then it will not have in general, and most specifically when it is a measuring device, a classically describable location and shape. Process 2 generates a quantum state (i.e., density matrix) that represents a sum (called a "mixture") of a 'continuum' of potential/possible worlds of the type that we can actuality perceive or experience, but does not specify which element (or set of elements) in this continuum will be "actualized" if someone looks.

This "mixture" of potentialities is sometimes called a "smear" of potentialities. Thus the quantum mechanical state of the macroscopic "pointer" on a measuring device is, by virtue of the process-2 evolution, "smeared out" over a continuous collection of potential locations along the dial. But that whole smear is not what is perceived if someone looks. It is the mind-dependent Process 1, not the mind-independent Process 2, that resolves the question of what our actual experiences are.

Process-2 evolution includes the interaction of the system of interest with the surrounding environment, but that "environmental decoherence" effect falls far short of specifying what an observer will experience/perceive if he looks! It is Process 1, not mere environmental decoherence, that provides that needed result.

As already described in Chap. 1, this Process 1 first selects, from the Process-2-generated continuum of potentialities, a particular perception that 'might' occur. Then 'nature' chooses, subject to the statistical Born Rule, either to accept the possibility selected by the observer, and then actualize the global consequences of that acceptance, or actualize the global consequences of rejecting the observer's proposal.

[The above description decomposes the standard vN description of an event that can involve, all at once, a large set of possibilities, into an ordered sequence of possibilities, each involving a single Yes/No question, as in the game of twenty questions. Thus the whole large set questions can be considered to be posed, one-by-one, with no passage of physical time, until a 'Yes' response eventually appears. This easily graspable formulation, proposed by Wheeler, is equivalent to the standard one, and more easily converted to the relativistic version demanded by RQFT. That latter version of the theory requires that a particular 3D "global instant now" be defined in association with each of nature's Yes-or-No responses, and that the associated global collapse be instituted along that 3D surface, which divides 4D space-time into an associated "past" and an associated "future". This will be discussed later.]

By means of the two processes, Process 1 and 2, the standard (Copenhagen-Von Neumann) approach elevates our inner mental selves, our egos, from passive spectators to active agents. From this orthodox quantum mechanical perspective, the basic difficulty with putative materialistic versions of quantum mechanics that leave our human mental choices out of the dynamics, is that they leave the theory burdened with (1): our useless conscious processes; and (2), a quantum mechanically evolving world with no means for selecting, from the Process-2-generated quantum smears of possibilities, what our actual perceptions will be. Moreover, the denial of the causal potency of our mental efforts is blatantly contradicted, empirically, by the ubiquitous experiences of everyday life. The materialists' claim that this experiential basis of our lives is an "illusion" rings hollow when the theory that makes this claim is found to be false, and is replaced by a hugely successful theory in which the ubiquitous daily experiences of the causal power of our mental intentions in the world of matter is rationally explained.

The Standard Copenhagen-Von Neumann Approach

The aforementioned 'smearing' difficulty is resolved in the standard quantum approach by bringing into the dynamics something beyond the Schrödinger equation, namely the probing actions of observing agents. The probing query might be, "Will my upcoming experience be that of the pointer on the measuring device lying between 5 and 5.01 on the dial?" A 'Yes' response on the part of nature consists of nature's delivering to the observer the query-defined possible experience, and reducing the quantum state of the entire universe to the part of its prior self compatible with that 'Yes' response. A 'No' answer will result in a corresponding reduction, but no immediate experiential feedback. This omission leaves room for another query to be posed with no passage of physical time. Thus millions of 'No's' can be produced by Nature with (little or) no passage of measured physical time.

The primary reality assumption in the realistically interpreted orthodox quantum field theory that I am describing is that the evolving quantum state (i.e., density matrix) of the universe is an element of reality. The behavior of this quantum state is concordant with the idea that it represents, as Heisenberg and the philosopher Alfred North Whitehead have emphasized, a collection of (Aristotelian) "potentialities for future experiences". This quantum potentiality normally evolves according to the definite Process 2, but, in order to become an 'actuality', a 'potentiality' must be 'actualized' by some other process, and the future is thus considered to be "open". In contrast, a future 'classical possibility' is mechanically predetermined to 'happen' or 'not happen' already at the birth of the universe, thereby precluding any possibility that our mental intentions and efforts can make any difference in what happens to our physical bodies.

In von Neumann's formulation, the purely atomic-physics-based dynamical process (Process 2) does not fail because a system is 'big'. It fails because the atom-based aspects of the dynamics are *only part of the causal story*. The causal, deterministic unitary Process 2 is disrupted by non-unitary Process-1 perceptual observations, which therefore have causal effects upon the physical/material world that are not caused by the purely matter-based Process 2. Thus materialism fails!

That is, the purely matter-based Process-2 evolution fails when that evolution comes into causal contact with the material correlates of our subjective experiences, which are the neural (or brain) correlates of our subjective experiences of probing and perceiving. No other failure of Process 2 is mentioned!

Von Neumann spends a lot of time and effort reducing the quantum mathematics to properties of so-called projection operators. These can be directly related to experiments that have just two alternative possible results, Yes or No, which can be associated with whether or not an observer perceives a specified response or fails to perceive such a response to his probing action. This association allows well-defined connections to be formed between von Neumann's mathematics and observer perceptions. If the answer is 'Yes' then the specified perception occurs. If the answer is 'No' then no perception occurs, for no perception can be all the perceptions other than the specified one.

This rule allows many immediate 'No' responses to be delivered by nature before the one 'Yes' in a multiple-choice question.

The purely mechanical atom-based Process-2 evolution fails when a measuring process is performed, due to the over-riding character of the Process-1 action.

Orthodox quantum mechanics is thus basically a description of this causal dynamical interaction between our conscious minds, which carry our perceptions, and our material atom-based brains, which contain the brain correlates of our probing actions and the responding perceptions.

The earlier classical mechanics is constitutionally unable to accommodate the twentieth-century empirical data. But the most elemental and ubiquitous source of empirical data is one's own daily experiencing of the ability of one's mental effort to influence one's bodily action. Who has not witnessed the intense struggle of the newborn infant to learn, by trial and error, which mental effort produces which perceived bodily response? To classify this first-hand empirical data as an "illusion" in order to salvage a theory that is known to be fundamentally false, and false in a way that is essentially an incorrect understanding of the connection between our conscious experiences and their brain counterparts, is neither rational nor scientific.

The quantum resuscitation of the causal power of our thoughts overturns the absurd classical notion that nature has endowed us with conscious minds whose only power and function is to delude us into believing that it is helping us to create a future that advances our felt values, while in actuality that future was predetermined 15 billon years ago.

Realistically interpreted orthodox quantum theory thus provides us with a non-materialistic science-based understanding of our own intrinsic nature. It is a theory that accounts *with spectacular accuracy* for the structure of the empirical facts about the external world discovered by atomic physicist during the twentieth century. Many competent physicists struggled unsuccessfully for a quarter of a century to comprehend those facts in every imaginable way concordant with the materialistic word view, until Heisenberg, in 1925, lifting that restriction, but clinging to the principle that the new theory should be built upon “observables”, and hence in some way upon us observers, broke the log-jam in such a decisive way that Pauli, Born, Jordan and others immediately jumped on board. Einstein, already in 1928, nominated Heisenberg, Born, and Jordan for the Nobel Prize, which was awarded to Heisenberg in 1932. The strangle-hold of materialism was broken simply by the need to accommodate the empirical data of atomic physics, but the ontological ramifications went far deeper, into the issue of our own human nature and the power of our thoughts to influence our psycho-physical future.

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