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MINDFUL UNIVERSE

Quantum Mechanics and the Participating Observer

With 9 Figures

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1 Science, Consciousness and Human Values

A tremendous burgeoning of interest in the problem of consciousness is now in progress. The grip of the behaviorists who sought to banish consciousness from science has finally been broken. This shift was ratified, for example, by the appearance several years ago of a special issue of Scientific American entitled *The Hidden Mind* (August 2002).

The lead article, written by Antonio Damasio, begins with the assertion: "At the start of the new millennium, it is apparent that one question towers above all others in the life sciences: How does the set of processes we call mind emerge from the activity of the organ we call brain?" He notes that some thinkers "believe the question to be unanswerable in principle", while: "For others, the relentless and exponential increase in knowledge may give rise to the vertiginous feeling that no problem can resist the assault of science *if only the science is right* and the techniques are powerful enough" (my emphasis). He notes that: "The naysayers argue that exhaustive compilation of all these data (of neuroscience) adds up to correlates of mental states but to nothing resembling *an actual mental state*" (his emphasis). He adds that: "In fact, the explanation of the physics related to biological events is still incomplete" and states that "the finest level of description of mind [...] might require explanation at the quantum level." Damasio makes his own position clear: "I contend that the biological processes now presumed to correspond to mind in fact are mind processes and will be seen to be so when understood in sufficient detail."

Damasio at least hints at the idea that "biological process [...] understood in sufficient detail" is a quantum understanding.

The possibility that quantum physics might be relevant to the connection between conscious process and brain process was raised also by Dave Chalmers, in his contribution 'The Puzzle of Conscious Experience' to *The Hidden Mind*. However, Chalmers effectively tied that possibility to the proposal put forth by Roger Penrose (1989, 1994) and, faulting that particular approach, rejected the general idea.

The deficiency of Penrose's approach identified by Chalmers is that it fails to bring in consciousness. It is about certain brain processes that may be related to consciousness, but "the theory is silent about how these processes might give rise to conscious experience. Indeed, the same problem arises with any theory of consciousness based only on physical processing."

Penrose's treatment does indeed focus on physical processing. But quantum theory itself is intrinsically psychophysical: as designed by its founders, and as used in actual scientific practice, it is ultimately a theory about the structure of our experience that is erected upon a radical mathematical generalization of the laws of classical physics.

Chalmers goes on to expound upon the 'explanatory gap' between, on the one hand, theoretical understanding of the behavioral and functional aspects of brain processes and, on the other hand, an explanation of how and why the performance of those functions should be accompanied by conscious experience. Such a gap arises in the classical approximation, but not in orthodox quantum theory, which is fundamentally a causal weaving together of the structure of our streams of conscious experiences, described in psychological terms, with a theoretical representation of the physical world described in mathematical language.

The conflating of Nature herself with the impoverished mechanical conception of it invented by scientists during the seventeenth century has derailed the philosophies of science and of mind for more than three centuries, by effectively eliminating the causal link between the psychological and physical aspects of nature that contemporary physics restores.

But the now-falsified classical conception of the world still exerts a blinding effect. For example, Daniel Dennett (1994, p. 237) says that his own thinking rests on the idea that "a brain was always going to do what it was caused to do by current, local, mechanical circumstances". But by making that judgment he tied his thinking to the physical half of Cartesian dualism, or its child, classical physics, and thus was forced in his book *Consciousness Explained* (Dennett 1991) to leave consciousness out, as he himself admits, and tries to justify, at the end of the book. By effectively restricting himself to the classical approximation, which squeezes the effects of consciousness out of the more accurate consciousness-dependent quantum dynamics, Dennett cuts himself off from any possibility of validly explaining the physical efficacy of our conscious efforts.

Francis Crick and Christof Koch begin their essay in *The Hidden Mind* entitled ‘The Problem of Consciousness’ with the assertion: “The overwhelming question in neurobiology today is the relationship between the mind and the brain.” But after a brief survey of the difficulties in getting an answer they conclude that: “Radically new concepts may indeed be needed – recall the modifications in scientific thinking forced on us by quantum mechanics. The only sensible approach is to press the experimental attack until we are confronted with dilemmas that call for new ways of thinking.”

However, the two cases compared by Crick and Koch are extremely dissimilar. The switch to quantum theory was forced upon us by the fact that we had a very simple system – consisting of a single hydrogen atom interacting with the electromagnetic field – that was so simple that it could be exactly solved by the methods of classical physics, but the calculated answer did not agree with the empirical results. There was initially no conceptual problem. It was rather that precise computations were possible, but gave wrong answers. Here the problem is reversed: precise calculations of the dynamical brain processes associated with conscious experiences are not yet possible, and hence have not revealed any mismatch between theory and experiment. The problem is, rather, a conceptual one: the concepts of classical physics that many neurobiologists are committed to using are logically inadequate because, unlike the concepts of quantum physics, they effectively exclude our conscious thoughts.

Dave Chalmers emphasizes this conceptual difficulty, and concludes that experimental work by neurobiologists is not by itself sufficient to resolve ‘The Puzzle of Conscious Experience’. Better concepts are also needed. He suggests that the stuff of the universe might be information, but then, oddly, rejects the replacement of classical physical theory, which is based on material substance, by quantum theory, which is built on an informational structure that causally links experienced increments of knowledge to physically described processes.

During the nineteenth century, before the precepts of classical physics had been shown to be false at the fundamental level, scientists and philosophers had good reasons to believe that the physical aspects of reality were causally closed: that the mathematically described physical aspects of nature were completely determined, by the laws of Nature, in terms of earlier properties of the same kind. However, even then this led to a certain unreasonableness noted by William James (1890, p. 138): consciousness seems to be “an organ, superadded to the other organs which maintain the animal in its struggle for existence; and the presumption of course is that it helps him in some way in this struggle, just as they do. But it cannot help him without being in some way efficacious and influencing the course of his bodily history." James went on to examine the circumstances under which consciousness appears, and ended up saying: "The conclusion that it is useful is, after all this, quite justifiable. But if it is useful it must be so through its causal efficaciousness, and the automaton-theory must succumb to common-sense" (James 1890, p. 144).

That was James's conclusion even at a time when deterministic classical physical theory seemed secure and unchallengeable, and the notion that we human beings are mechanical automata was the rationally inescapable consequence of a triumphant physics. James's analysis was vindicated, however, by the ascendancy of quantum mechanics during the first half of the twentieth century. The aim of this book is to describe the development of this revised conceptualization of the connection between our minds and our brains, and the consequent revision of the role of human consciousness in the unfolding of reality. This revision in our understanding of ourselves and our place in nature infuses the subject with a significance that extends far beyond the narrowly construed boundaries of science. These changes penetrate to the heart of important sociological and philosophical issues.

Science has improved our lives in many ways. It has lightened the load of tedious tasks and expanded our physical powers, thereby contributing to a great flowering of human creativity. On the other hand, it has given us also the capacity to ravage the environment on an unprecedented scale and to obliterate our species altogether. Yet along with this fatal power it has provided a further offering which, though subtle in character and still hardly felt in the minds of men, may ultimately be its most valuable contribution to human civilization, and the key to human survival.

Science is not only the enterprise of harnessing nature to serve the practical needs of humankind. It is also part of man's unending search for knowledge about the universe and his place within it. This quest is motivated not solely by idle curiosity. Each of us, when trying to establish values upon which to base conduct, is inevitably led to the question of one's place in the greater whole. The linkage of this philosophical inquiry to the practical question of personal values is no mere intellectual abstraction. Martyrs in every age are vivid reminders of the fact that no influence upon human conduct, even the instinct for bodily self-preservation, is stronger than beliefs about one's relationship to the rest of the universe and to the power that shapes it. Such beliefs form the foundation of a person's self-image, and hence, ultimately, of personal values.

It is often claimed that science stands mute on questions of values: that science can help us to achieve what we value once our priorities are fixed, but can play no role in fixing these weightings. That claim is certainly incorrect. Science plays a key role in these matters. For what we value depends on what we believe, and what we believe is strongly influenced by science.

A striking example of this influence is the impact of science upon the system of values promulgated by the church during the Middle Ages. That structure rested on a credo about the nature of the universe, its creator, and man's connection to that creator. Science, by casting doubt upon that belief, undermined the system of values erected upon it. Moreover, it put forth a credo of its own. In that 'scientific' vision we human beings were converted from sparks of divine creative power, endowed with free will, to mechanical automata – to cogs in a giant machine that grinds inexorably along a preordained path in the grip of a blind causal process.

This material picture of human beings erodes not only the religious roots of moral values but the entire notion of personal responsibility. Each of us is asserted to be a mechanical extension of what existed prior to his or her birth. Over that earlier situation one has no control. Hence for what emerges, preordained, from that prior state one can bear no responsibility.

This conception of man undermines the foundation of rational moral philosophy, and science is doubly culpable: It not only erodes the foundations of earlier value systems, but also acts to strip man of any vision of himself and his place in the universe that could be the rational basis for an elevated set of values.

During the twentieth century this morally corrosive mechanical conception of nature was found to be profoundly incorrect. It failed not just in its fine details, but at its fundamental core. A vastly different conceptual framework was erected by the atomic physicists Werner Heisenberg, Niels Bohr, Wolfgang Pauli and their colleagues. Those scientists were forced to a wholesale revision of the entire subject matter of physical theory by the peculiar character of the new mathematical rules, which were invariably validated by reliable empirical data.

The earlier 'classical' physics had emerged from the study of the observed motions of the planets and large terrestrial objects, and the entire physical universe was, correspondingly, conceived to be made, essentially, out of miniaturized versions of these large visible objects.

Called “solid, massy, hard, impenetrable moveable particles” by Newton (1704), these tiny objects were conceived to act upon each other by contact interactions, much like billiard balls, except for the mysterious action at a distance called gravity. Newton himself rejected the idea that gravity could really act at distance without any intervening carrier. Nevertheless, provisional rules were found that were imagined to control the behavior of these tiny entities, and thus also the objects composed of them. These laws were independent of whether or not anyone was observing the physical universe: they took no special cognizance of any acts of observation performed by human beings, or of any knowledge acquired from such observations, or of the conscious thoughts of human beings. All such things were believed, during the reign of classical physics, to be completely determined, insofar as they had any physical consequences, by the physically described properties and laws that acted wholly mechanically at the microscopic scale. But the baffling features of new kinds of data acquired during the twentieth century caused the physicists who were studying these phenomena, and trying to ascertain the laws that governed them, to turn the whole scientific enterprise upside down.

Perhaps I should say that they turned right side up what had been upside down. For the word ‘science’ comes from the Latin word ‘scire’, ‘to know’, and what the founders of the new theory claimed, basically, is that the proper subject matter of science is not what may or may not be ‘out there’, unobserved and unknown to human beings. It is rather what we human beings can know, and can do in order to know more. Thus they formulated their new theory, called quantum mechanics, or quantum theory, around the knowledge-acquiring actions of human beings, and the knowledge we acquire by performing these actions, rather than around a conjectured causally sufficient mechanical world. The focus of the theory was shifted from one that basically ignored our knowledge to one that is about our knowledge, and about the effects of the actions that we take to acquire more knowledge upon what we are able to know.

This modified conception differs from the old one in many fascinating ways that continue to absorb the interest of physicists. However, it is the revised understanding of the nature of human beings, and of the causal role of human consciousness in the unfolding of reality, that is, I believe, the most exciting thing about the new physics, and probably, in the final analysis, also the most important contribution of science to the well-being of our species.

The rational foundation for this revised conceptual structure emerged from the intense intellectual struggles that took place during the twenties, principally between Niels Bohr, Werner Heisenberg, and Wolfgang Pauli. Those struggles replaced the then-prevailing Newtonian idea of matter as "solid, massy, hard, impenetrable, moveable particles" with a new concept that allowed, and in fact required, an entry into the causal structure of the physical effects of conscious decisions made by human subjects. This radical change swept away the meaningless billiard-ball universe, and replaced it with a universe in which we human beings, by means of our value-based intentional efforts, can make a difference first in our own behaviors, thence in the social matrix in which we are imbedded, and eventually in the entire physical reality that sustains our streams of conscious experiences.

The existing general descriptions of quantum theory emphasize puzzles and paradoxes in a way that tend to make non-physicists leery of using in any significant away the profound changes in our understanding of both man and nature wrought by the quantum revolution. Yet in the final analysis quantum mechanics is *more* understandable than classical mechanics because it is more deeply in line with our common sense ideas about our role in nature than the 'automaton' notion promulgated by classical physics. It is the three hundred years of indoctrination with mechanistic ideas that now makes puzzling a conception of ourselves that is fully concordant with both normal human intuition and the full range of empirical facts.

The founders of quantum mechanics presented this theory to their colleagues as essentially a set of rules about how to make predictions about the empirical feedbacks that we human observers will experience if we take certain actions. Classical mechanics can, of course, be viewed in exactly the same way, but the two theories differ profoundly in their logical and mathematical structures, and consequently, and even more profoundly, in what they purport to be fundamentally about.

In classical mechanics the state of any system, at some fixed time t, is defined by giving the location and the velocity of every particle in that system, and by giving also the analogous information about the electromagnetic and gravitational fields. All observers and their acts of observation are conceived to be simply parts or aspects of the continuously evolving fully mechanically pre-determined physically described universe. A person's stream of consciousness is considered to be some mysterious, but causally irrelevant or redundant, by-product or counterpart of his or her classically conceived and described brain activity.

But this classical idea that our conscious experiences are just some idea-like counterparts of a continuously evolving brain state encounters a certain difficulty. The classically conceived evolution of the brain is continuous, and hence the number of different physical states that occur during any temporal interval of continuous change is infinite. Thus a natural mind–brain connection should give, it would seem, a continuously changing state of consciousness, composed of parts in a way analogous to the neural activity that it represents. But this surmise seems at odds with the empirical evidence. According to William James (1911):

> [...] a discrete composition is what actually obtains in our perceptual experience. We either perceive nothing, or something already there in a sensible amount. This fact is what is known in psychology as the laws of the 'threshold'. Either your experience is of no content, of no change, or it is of a perceptible amount of content or change. Your acquaintance with reality grows literally by buds or drops of perception. Intellectually and on reflection you can divide these into components, but as immediately given they come totally or not at all.

A similar discreteness is the signature of quantum phenomena: the quantum wave is spread out over a vast region covering many detectors, but only one detector fires, the rest do not. The element of discreteness, the 'Yes' or 'No' of the Geiger counter's 'click' is an elemental feature of quantum theory. Thus Bohr (1962, p. 60) speaks of: "The element of wholeness, symbolized by the quantum of action and completely foreign to classical physical principles."

In psychology the identity and form of the percept that actually enters into a stream of consciousness depends strongly on the intention of the probing mind: a person tends to experience what he or she is looking for, provided the potentiality for that experience is present. The observer does not create what is not potentially there, but does participate in the extraction from the mass of existing potentialities individual items that have interest and meaning to the perceiving self.

Quantum theory exhibits, as we shall see, a similar feature. Thus both psychology and physics, when examined in depth, reveal observer-influenced whole elements that seem "foreign to classical physical principles".

Insofar as it has been tested, the new theory, quantum theory, accounts for all the observed successes of the earlier physical theories, and also for the immense accumulation of new data that the earlier concepts cannot accommodate. But, according to the new conception, the *physically described world* is built not out of bits of matter, as matter was understood in the nineteenth century, but out of objective *tendencies* – potentialities – for certain discrete, whole *actual events* to occur. Each such event has both a psychologically described aspect, which is essentially an increment in knowledge, and also a physically described aspect, which is an action that *abruptly changes* the mathematically described set of potentialities to one that is concordant with the increase in knowledge. This coordination of the aspects of the theory that are described in physical/mathematical terms with aspects that are described in psychological terms is what makes the theory practically useful. Some empirical predictions have been verified to the incredible accuracy of one part in a hundred million.

The most radical change wrought by this switch to quantum mechanics is the injection directly into the dynamics *of certain choices made by human beings about how they will act*. Human actions enter, of course, also in classical physics. But the two cases are fundamentally different. In the classical case the way a person acts is fully determined in principle by the physically described aspects of reality alone. But in the quantum case there is *an essential gap in physical causation*. This gap is generated by Heisenberg's uncertainty principle, which opens up, at the level of human actions, a range of alternative possible behaviors between which the physically described aspects of theory are in principle unable to choose or decide. But this loss-in-principle of causal definiteness, associated with a loss of knowable-in-principle physically describable information, opens the way, logically, to an input into the dynamics of another kind of possible causes, which are eminently knowable, both in principle and in practice, namely our conscious choices about how we will act. These interventions in the dynamics take the form of specifications of *new boundary conditions*.

The specifications of boundary conditions is, of course, the traditional job of the experimenters. But in classical physics the only needed setting of boundary conditions is the one done by God at the beginning of time. On the other hand, the conventional laws of quantum mechanics have both a dynamical opening for, and a logical need for, additional choices made later on. Thus contemporary orthodox physics delegates some of the responsibilities formerly assigned to an inscrutable God, acting in the distant past, to our present knowable conscious actions.

Niels Bohr emphasized this freedom of action 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. (Bohr 1958, p. 73)

> To my mind, there is no other alternative than to admit that, in this field of experience, we are dealing with individual phenomena and that our possibilities of handling the measuring instruments allow us only to make a choice between the different complementary types of phenomena that we want to study. (Bohr 1958, p. 51)

In John von Neumann's rigorous mathematical formulation of quantum mechanics the effects of these free choices upon the physically described world are specifically called 'interventions' (von Neumann 1955/1932, pp. 358, 418). These choices are 'free' in the sense that they are not coerced, fixed, or determined by the physically described aspects of the theory. Yet these choices, which are not fixed or determined by any law of orthodox contemporary physics, and which *seem to us* to depend partly upon 'reasons' based on felt values, definitely have potent effects upon the physically described aspects of the theory. These effects are specifically described by the theory.

Nothing like this effective action of mind upon physically described things exists in classical physics. There is nothing in the principles of classical physics that requires, or even hints at, the existence of such things as thoughts, ideas, and feelings, and certainly no opening for aspects of nature not determined by the physically describable aspects of nature to 'intervene' and thereby influence the future physically described structure. In fact, it is precisely the absence from classical physics of any notion of experiential-type realities, or of any job for them to do, or of any possibility for them to do anything not already done locally by the mechanical elements, that has been the bane of philosophy for three hundred years. Eliminating this scientifically unsupported precept of the causal closure of the physical opens the way to a new phase of science-based philosophy.

The preceding remarks give a brief overview of the theme of this work. I shall begin my more detailed account of these twentieth century developments in science by emphasizing, in the words of the founders themselves, the central role played in the new theory by 'our knowledge'.

2 Human Knowledge as the Foundation of Science

In the introduction to his book *Quantum Theory and Reality* the philosopher of science Mario Bunge (1967, p. 4) said:

> The physicist of the latest generation is operationalist all right, but usually he does not know, and refuses to believe, that the original Copenhagen interpretation – which he thinks he supports – was squarely subjectivist, i.e., nonphysical.

Let there be no doubt about this point. The original form of quantum theory is subjective, in the sense that it is forthrightly about relationships among conscious human experiences, and it expressly recommends to scientists that they resist the temptation to try to understand the reality responsible for the correlations between our experiences that the theory correctly describes. The following brief collection of quotations by the founders gives a conspectus of the Copenhagen philosophy:

> The conception of objective reality of the elementary particles has thus evaporated not into the cloud of some obscure new reality concept but into the transparent clarity of a mathematics that represents no longer the behavior of particles but rather our knowledge of this behavior. (Heisenberg 1958a, p. 100)

> [...] the act of registration of the result in the mind of the observer. The discontinuous change in the probability function [...] takes place with the act of registration, because it is the discontinuous change in our knowledge in the instant of registration that has its image in the discontinuous change of the probability function. (Heisenberg 1958b, p. 55)

> When the old adage "Natura non facit saltus" (Nature makes no jumps) is used as a basis of a criticism of quantum theory, we can reply that certainly our knowledge can change suddenly, and that this fact justifies the use of the term 'quantum jump'. (Heisenberg 1958b, p. 54)

> It was not possible to formulate the laws of quantum mechanics in a fully consistent way without reference to the consciousness. (Wigner 1961b, p. 169)

> 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. (Bohr 1934, p. 18)

> Strictly speaking, the mathematical formalism of quantum mechanics merely offers rules of calculation for the deduction of expectations about observations obtained under well-defined classical concepts. (Bohr 1963, p. 60)

> [...] the appropriate physical interpretation of the symbolic quantum mechanical formalism amounts only to prediction of determinate or statistical character, pertaining to individual phenomena appearing under conditions defined by classical physics concepts. (Bohr 1958, p. 64)

The references to 'classical (physics) concepts' is explained by Bohr as follows:

> [...] it is imperative to realize that in every account of physical experience one must describe both experimental conditions and observations by the same means of communication as the one used in classical physics. Bohr (1958, p. 88)

> [...] we must recognize above all that, even when phenomena transcend the scope of classical physical theories, the account of the experimental arrangement and the recording of observations must be given in plain language supplemented by technical physical terminology. (Bohr 1958)

Bohr is saying that scientists do in fact use, and must use, the concepts of classical physics in communicating to their colleagues the specifications on how the experiment is to be set up, and what will constitute a certain type of outcome. He in no way claims or admits that there is an actual objective reality out there that conforms to the precepts of classical physics.

In his book *The Creation of Quantum Mechanics and the Bohr–Pauli Dialogue*, the historian John Hendry (1984) gives a detailed account of the fierce struggles by such eminent thinkers as Hilbert, Jordan, Weyl, von Neumann, Born, Einstein, Sommerfeld, Pauli, Heisenberg, Schroedinger, Dirac, Bohr and others, to come up with a rational way of comprehending the data from atomic experiments. Each man had his own bias and intuitions, but in spite of intense effort no rational comprehension was forthcoming. Finally, at the 1927 Solvay conference a group including Bohr, Heisenberg, Pauli, Dirac, and Born come into concordance on a solution that came to be called the Copenhagen interpretation, due to the central role of Bohr and those working with him at his institute in Denmark.

Hendry says: “Dirac, in discussion, insisted on the restriction of the theory’s application to our knowledge of a system, and on its lack of ontological content.” Hendry summarized the concordance by saying: “On this interpretation it was agreed that, as Dirac explained, the wave function represented our knowledge of the system, and the reduced wave packets our more precise knowledge after measurement.”

These quotations make it clear that, in direct contrast to the ideas of classical physical theory, orthodox Copenhagen quantum theory is about ‘our knowledge’. We, and in particular our mental aspects, have entered into the structure of basic physical theory.

This profound shift in physicists’ conception of the basic nature of their endeavor, and of the meanings of their formulas, was not a frivolous move: it was a last resort. The very idea that in order to comprehend atomic phenomena one must abandon physical ontology, and construe the mathematical formulas to be directly about the knowledge of human observers, rather than about external reality itself, is so seemingly preposterous that no group of eminent and renowned scientists would ever embrace it except as an extreme last measure. Consequently, it would be frivolous of us simply to ignore a conclusion so hard won and profound, and of such apparent direct bearing on our effort to understand the connection of our conscious thoughts to our bodily actions.

Einstein never accepted the Copenhagen interpretation. He said:

> What does not satisfy me, from the standpoint of principle, is its attitude toward what seems to me to be the programmatic aim of all physics: the complete description of any (individual) real situation (as it supposedly exists irrespective of any act of observation or substantiation). (Einstein 1951, p. 667; the parenthetical word and phrase are part of Einstein’s statement.)

and

> What I dislike in this kind of argumentation is the basic positivistic attitude, which from my view is untenable, and which

> seems to me to come to the same thing as Berkeley's principle, esse est percipi. [Transl: To be is to be perceived] (Einstein 1951, p. 669)

Einstein struggled until the end of his life to get the observer's knowledge back out of physics. He did not succeed! Rather he admitted (ibid. p. 87) that:

> It is my opinion that the contemporary quantum theory constitutes an optimum formulation of the [statistical] connections.

He also referred (ibid, p. 81) to:

> [...] the most successful physical theory of our period, viz., the statistical quantum theory which, about twenty-five years ago took on a logically consistent form. This is the only theory at present which permits a unitary grasp of experiences concerning the quantum character of micro-mechanical events.

One can adopt the cavalier attitude that these profound difficulties with the classical conception of nature are just some temporary retrograde aberration in the forward march of science. One may imagine, as some do, that a strange confusion has confounded our best minds for seven decades, and that the weird conclusions of physicists can be ignored because they do not fit a tradition that worked for two centuries. Or one can try to claim that these problems concern only atoms and molecules, but not the big things built out of them. In this connection Einstein said (ibid, p. 674): "But the 'macroscopic' and 'microscopic' are so inter-related that it appears impracticable to give up this program [of basing physics on the 'real'] in the 'microscopic' domain alone."

These quotations document the fact that Copenhagen quantum theory brings human consciousness into physical theory in an essential way. But how does this radical change in basic physics affect science's conception of the human person?

To answer this query I begin with a few remarks on the development of quantum theory.

The original version of quantum theory, called the Copenhagen quantum theory, or the Copenhagen interpretation, is forthrightly pragmatic. It aims to show how the mathematical structure of the theory can be employed to make useful, testable predictions about our future possible experiences on the basis of our past experiences and the forms of the actions that we choose to make. In this initial version of the theory the brains and bodies of the experimenters, and also their measuring devices, are described fundamentally in empirical terms: in terms of our experiences/perceptions pertaining to these devices and their manipulations by our physical bodies. The devices are treated as extensions of our bodies. However, the boundary between our empirically described selves and the physically described system we are studying is somewhat arbitrary. The empirically described measuring devices can become very tiny, and physically described systems can become very large, This ambiguity was examined by von Neumann (1932) who showed that we can consistently describe the entire physical world, including the brains of the experimenters, as the physically described world, with the actions instigated by an experimenter's stream of consciousness acting directly upon that experimenter's brain. The interaction between the psychologically and physically described aspects in quantum theory thereby becomes the mind–brain interaction of neuroscience and neuropsychology.

It is this von Neumann extension of Copenhagen quantum theory that provides the foundation for a rationally coherent ontological interpretation of quantum theory – for a putative description of what is really happening. Heisenberg suggested an ontological description in his 1958 book *Physics and Philosophy* and I shall adhere to that ontology, formulated within von Neumann's framework in which the brain, as part of the physical world, is described in terms of the quantum mathematics. This localizes the mind–matter problem at the interface between the quantum mechanically described brain and the experientially described stream of consciousness of the human agent/observer.

My aim in this book is to explain to non-physicist the interplay between the psychologically and physically described components of mind–brain dynamics, as it is understood within the orthodox (von Neumann–Heisenberg) quantum framework.