Title
CONSCIOUSNESS AND VALUES IN THE QUANTUM UNIVERSE

Author
Stapp, H.P.

Publication Date
1983-04-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

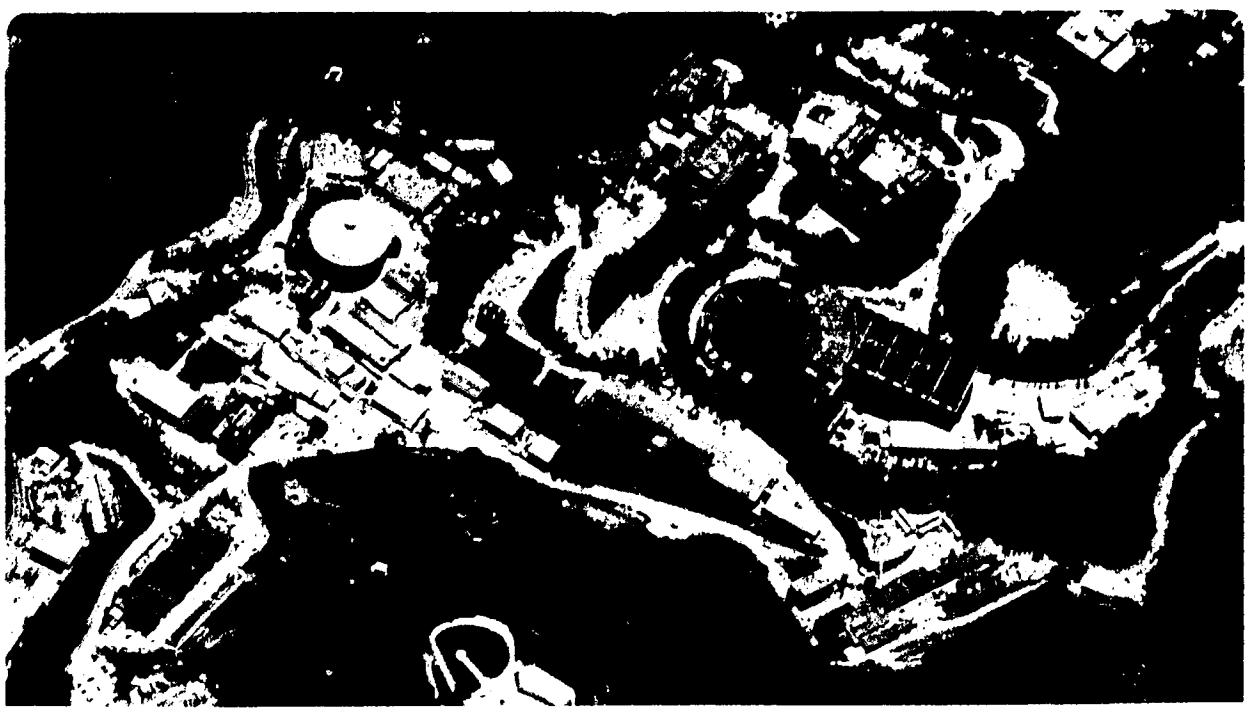
Physics, Computer Science & Mathematics Division

Submitted for publication

CONSCIOUSNESS AND VALUES IN THE QUANTUM UNIVERSE

Henry P. Stapp

April 1983



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

April 1983

LBL-15363

Consciousness and Values in the Quantum Universe*

Henry P. Stapp

Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

Abstract

Application of quantum mechanical description to neurophysiological processes produces a natural unification of the physical and humanistic sciences. The categories of thought used to represent physical and psychical processes become united. Moreover, the mechanical conception of man created by classical physics is replaced by a profoundly different quantum conception. This revised image of man generates human values based on contemporary science.

---

*This research was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

1. Science and Human Values

Science has brought immense benefits to man, but has indirectly created problems such as pollution, over-poplulation, alienation, and human survival itself. Solving these problems demands judgments between conflicting human values.

It is often maintained that science stands mute on the question of human values. This is not correct. What men value depends on what they believe, and what they believe is increasingly determined by science. Indeed, the contemporary disarray in the field of human values was largely caused by science, for science destroyed the credibility of the myths upon which prior value systems were based.

The notion that science is irrelevant to the question of human values arises from a failure to distinguish science from the classical physics of earlier centuries. Classical physics reduced man to a machine whose every action and thought was preordained at the beginning of time. The concepts of aims, responsibilities, and values find no place in this mechanical conception of man.

Quantum theory generates an altogether different conception of man, and his role in nature: it gives man a new self-image. But self-image is the base from which values spring: what a man values depends on what he conceives himself to be. Thus quantum theory, by creating a new conception of man profoundly different from that of classical physics, provides the foundation for science-based human values.

Man largely controls today the physical variables of human existence. The critical determinants lie now in the realm of ideas: the force of ideas is paramount. Thus the quantum theoretical conception of man, recognized and accepted first by scientists, and eventually by mankind in general, can be expected to exercise decisive control over the course of future human events. The principal service of science to man may therefore be, not the

taming of the forces of nature that lie outside of man, but rather the guidance, through illumination, of the power of man himself.

2. Quantum Uncertainty and Freedom

Quantum theory has brought profound changes to the physicists' view of nature. These changes are rooted in empirical phenomena, and are expressed in abstract mathematical language. Yet the essential difference between quantum theory and the earlier classical conception of nature can be understood intuitively.

Intuitively, the most peculiar feature of classical physics is the cataclysmic nature of the original creative act: the entire universe is brought into being and set in motion in one immense creative act , which is then followed by nothing but a mere automatic running through of what was ordained by that single act. This later follow-up phase seems pointless. Even the idea that something is actually happening is puzzling, since the entire space-time course of events is already fixed, and hence somehow already there. Countless philosophical puzzles have arisen from this peculiar conception of the way nature works.

A different viewpoint is possible. One can suppose that the creative process consists of not just one single act, but rather a sequence of acts each of which further reduces the set of "possible worlds". Each of these "possible worlds" is an entire spacetime history: it is a set of complete spacetime trajectories, one for each particle in the universe, together with an associated set of spacetime fields. Each of these "possible worlds" obeys the laws of physics. Each "act" is an act of reduction of possibilities: it eliminates some of the possibilities.

One may further suppose that after some act all of the then-possible worlds differ only imperceptibly, at some particular time. As time progresses these imperceptible differences will, in accordance with the laws of motion, necessarily develop into perceptible differences. A new creative act then reduces the set of possible worlds to a subset that encompasses only imperceptible differences at some later time, and so on. In this way creation is transformed from a single cataclysmic event to a gradual process.

The deterministic laws of motion remain inviolate. But continuing freedom is maintained by distributing the freedom traditionally associated with the choice of initial conditions among the acts of the sequence.

In the framework of classical physics this idea of gradual creation is *ad hoc.* It might be proposed on philosophic grounds, and is compatible with the classical laws of physics, but it is not demanded, or even suggested, by the mathematical structure of classical physics itself. In quantum theory the situation is altogether different.

The essential difference between classical physics and quantum theory is that in classical physics no principle precludes the occurrence of a single creative act that reduces the set of possible worlds to a set containing only one such world. The continual regeneration of perceptibly different possibilities would then be terminated. But in quantum theory the uncertainty principle entails that even the most restrictive set of possibilities compatible with the basic mathematical structure of the theory will, in any realistic situation, develop in the course of time into a set of possibilities that encompass perceptible differences. Thus the continuing regeneration of perceptible differences is built into the basic structure of the theory. The theory itself consequently demands a continuing sequence of acts of reduction, if the world as represented by the wave function of the theory is to be in accord with our perceptions.

These recurring acts of reduction are formalized in quantum theory as von Neumann processes of type one, or as the closely related "reduction of the wave packet". The reduction of possibilities effected by each such act, like the choice among possible initial conditions, is not fixed by the deterministic laws of the theory: it is random or stochastic. It constitutes an element of freedom superimposed on the deterministic laws of motion.

3. Application to Brain Processes

Consider now the neurological functioning of a human brain. The function of the brain is to transform arriving information into appropriate responses. The brain must devise and initiate a coherent set of responses that can be simultaneously carried out.

Inhibitory connections are an important feature of brain neurophysiology. They inhibit certain patterns of neuronal and electro-chemical activity, but leave uninhibited an immense collection of possible patterns of excitation. High-level brain activity can be regarded as the dynamical interplay among such patterns.

Recent detailed model studies [1] of brain dynamics indicate that the highly nonlinear character of the controlling dynamical equations causes the evolving patterns of cortical excitations to depend very sensitively on the values of the synaptic parameters, particularly in the critical regions of phase transitions. The values of the synaptic parameters are controlled in turn by quantum processes. Thus the possibility arises that brain processes associated with conscious action may operate near these critical points and hence be very sensitive to quantum effects. It is then possible for the patterns of excitations that initiate perceptually different alternative possible courses of action to be simultaneously present in the (mixture of) wave functions that represent the brain. A choice among the branches of the wave function that initiate these perceptually different alternative possible courses of action would be, functionally, a choice among these different possible courses of action. It would be represented in quantum theory by a reduction of wave packet to the corresponding branch.

It is a consequence of von Neumann's analysis of the process of measurement that reduction of wave packets can occur at this macroscopic level: it need not occur at the microscopic level of the individual synaptic processes.

We may suppose, for the sake of definiteness, that not all, or even most, reductions are associated with consciousness. The other reductions can be assumed to keep the universe roughly in accord with some classical picture of nature. The problem of specifying precisely the conditions under which these other reductions occur is not faced by quantum theory, and will not be addressed here. The focus here is on those special reductions that are associated with brain processes.

4. Elements of a Theory of Consciousness

In the mentally healthy individual conscious processes provide direction in situations that are novel or require long-term planning. It is here proposed that the physical basis of conscious processes resides in a certain set of patterns of brain excitation. Each of these patterns tends to initiate a course of action, which may be either a perceptible physical action or a conscious mental action.

It is also proposed that the nonlinear character of the brain processes associated with conscious action causes the quantum effects present at the synaptic level to become enhanced to the extent that the wave function (mixture) representing the brain contains branches that describe alternative patterns of excitations that tend to initiate alternative possible courses of action. The act of choosing one of these courses of action is then identified as both a psychical and physical act: the subjectively felt act of selecting a course of action is represented in our theoretical construction of physical reality by the reduction of wave packet that selects this course of action. Thus what is "felt" at the psychical level is identical to what "happens" at the physical level, namely the selection of a certain course of action.

Recall and self-reference are important elements of conscious thought. It is assumed that each pattern of excitation corresponding to a conscious act is, by virtue of its temporary existence, etched into the structure of the brain by means of a conditioning of the synaptic junctions active during that original excitation and that, consequently, subsequent excitations of parts of the pattern tend to excite other parts of it. Each pattern corresponding to a conscious act will then generally be largely constructed from fragments of patterns corresponding to prior conscious acts. Recall and self-reference are thereby accommodated, since the informational content of the present act will contain parts of the informational content of prior acts and the present experienced self will be constructed largely from reassembled fragments representing parts of earlier experienced

selves.

This quantum theoretical approach to consciousness, though still in a rudimentary stage, is far more natural than approaches based on classical physics. In classical physics brain activity is described by a collection of spacetime variables. Thus a connection between mind and matter requires a connection between things that are totally dissimilar, and belong to different categories of ideas: a collection of numbers representing the motions of billions of particles is identified with a unified conscious thought. But classical physics is essentially reductionistic, and has no natural place for superimposed holistic entities. Moreover, the directly experienced control aspect of consciousness is not reconcilable with classical physics: the course of events, as described by classical physics, is exactly the same whether consciousness is present or not.

In the present quantum theoretical approach consciousness is considered built from conscious acts. The conscious act that selects a course of action is represented naturally in physical theory as the act of reduction that selects this course of action. There is no arbitrary, or *ad hoc*, or mysterious correspondence that has to be cooked up. Instead there is simply the identification of the felt act of selecting a course of action with its naturally occurring counterpart in physical theory, namely the act of wave packet reduction that selects this course of action. This conception of the way nature works gives to man the role in nature he has always intuitively felt was his, and places the deterministic physical laws in their proper perspective as representations of certain statistical properties of the collection of free acts that constitute the process of creation.

Classical physics has no naturally occurring counterpart to the quantum-theoretic act of reduction of possibilities that is the basis of the mind-brain connection proposed here.

5. Historical Background

The idea that the stochastic element of quantum theory is connected to free-will is a natural concomitant of quantum thinking. Yet the founders of quantum theory avoided claiming any such connection. Bohr, for example, though he drew repeated analogies between physical and psychological phenomena, was characteristically cautious about suggesting a more direct connection: "...it is clear to the writer that for the time being we must be content with more or less appropriate analogies. Yet it may well be that behind these analogies there lies not only a kinship with regard to epistemological matters, but that a more profound relationship is hidden behind the fundamental biological problems which are directly connected to both sides." [2] "... it is obviously a quite open question whether the information we have acquired of the laws describing atomic phenomena provides us with a sufficient basis for tackling the problem of living organisms, ..., " [3] "the strict application of those concepts adapted to our description of inanimate nature might stand in a relationship of exclusion to the consideration of the laws of the phenomena of life." [4]

Bohr was able to avoid these fundamental issues by adopting a pragmatic position in whch quantum theory was regarded as merely a set of rules for calculating correlations among observations described in classical language [5]. This effectively placed the brains of the community of human observers of atomic systems outside the systems they were observing.

Heinsenberg's position was similar: "...what 'happens'... applies to the physical not the psychical act of observation, and we may say that the transition from 'possible' to 'actual' takes place as soon as the interaction of the object with the measuring devices has taken place, and thereby the rest of the world has come into play; it is not connected with the act of registration of the result in the mind of the observer" [6].

von Neumann [7], on the other hand, traced the

development of the wave function into the human brain. However, the purpose of that study was to demonstrate the validity of the principle of psycho-physical parallelism, in the sense that the boundary between the parts of the world described in physical and psychological terms, respectively, could be shifted over wide ranges without significantly affecting testable predictions. The possibility of shifting this boundary out to the furthest possible division between the observed system and macroscopic observing system was in general accord with Bohr and Heisenberg's idea that the boundary ought to be placed in this position. In this way the question of the connection between the brain and consciousness was circumvented, at least for questions concerning observations of atomic phenomena not themselves localized in human brains.

Wigner [8] explicitly conjectured a connection between free-will and quantum stochasticity, but did not specify the relationship between the subjective act and its physical counterpart in the neurophysiological activity of the brain.

The reluctance of the founders of quantum theory to speculate on this aspect of the mind-matter connection was, in view of the then-existing undeveloped state of neurophysiology, in line with the methodology of science. Today, however, the situation is quite different. On the one hand, the associative and nonassociative learning patterns of simple organisms, and the concomitant development of short- and long-term memory structures are now being empirically related to specific chemical processes at the synaptic junctions between neurons. [9] These studies provide a scientific basis for extrapolations to the more complex neurophysiological processes and concomitant behavior patterns associated with human consciousness. Furthermore, the complexities of neocortical dynamics are now beginning to be analyzed by the powerful methods of modern nonlinear nonequilibrium statistical dynamics. [1] Thus brain research is rapidly approaching the stage where the methodology of science requires formulations of proposals regarding the connection between consciousness and neurophysiological processes.

The most prominent of such proposals are probably those of Eccles [10], Sperry [11], and Walker [12]. The theory of Eccles can be characterized as "the ghost in the machine": an essentially human intelligence resides outside the brain and accomplishes its aims by a gentle manipulation of critical neuronal activities. Such an approach is, I believe, tantamount to abandoning science: the introduction of such potent and unconstrained entities into the theoretical structure probably renders crucial empirical tests unattainable. Sperry, on the other hand, introduces consciousness as a concomitant to holistic collective actions, and ascribes to it a controlling or guiding role. But he does not specifically appeal to quantum theory. Yet classical physics is, by its basic nature, reductionistic. It allows no holistic controlling agent: the course of events is determined in principle by reductionistic analysis, and no holistic control can be superposed.

Walker's model is fundamentally quantum mechanical, but associates free-will with a hidden variable that enters into equations of motion in much the same way as usual physical variables. This conception is exceedingly restrictive, but the restrictions do not appear to be of a testable kind. That is, the predictions that are eventually derived do not appear to be sensitive to this restrictive assumption, which reduces the holistic or integrative qualities of consciously felt acts to sets of variables analogous to those used in reductionist physical theories.

A more important distinction between Walker's proposal and the one described here is his introduction of a special mechanism involving memory-coded RNA, distributed throughout the brain, to mediate a tunneling process that effectively propagates the wave functions of individual electrons over large parts of the brain, in order to obtain a macroscopic spread of the wave functions associated with conscious process. This special mechanism appears unnecessary. The macroscopic spread of the wave functions whose reductions are associated with conscious acts can be generated in a more natural way by the neural circuitry of the brain. The calculations of Ref. [1] indicate that small changes in the synaptic parameters can lead to moderate changes

in the resultant macroscopic firing patterns. If the small changes arise from quantum uncertainties then the resulting macroscopic firing patterns will be represented by wave functions that have amplitudes that correspond, before any reduction has occurred, to a quantum superposition of different macroscopic patterns. The emergence of the macroscopically different patterns can be driven by feedback mechanisms that systematically suppress all patterns whose probabilities have not been enhanced by conditioning. In accordance with studies on learning it is supposed that activation of a firing pattern conditions the synaptic junctions in a way that effectively records a memory of the firing pattern, and creates a tendency for it to recur.

According to the many-world [13] (or many-minds) interpretation of quantum theory these branches identified by distinct memory structure will become essentially dynamically distinct, due to quantum linearity and the non-overlap property of distinct memory patterns. This is a consequence of essentially von Neumann's analysis [7]. The important thing is that even though the different patterns represent macroscopically different systems there is no empirical need for the wave function to collapse: the separate branches could continue to exist, in some absolute sense, though at the level of individual human experience the two branches would no longer be simultaneously present. The only evidence for a reduction is the subjective feeling, in some cases, that a conscious choice has been made. In distinction to the situation in classical physics there is now no reason to deny the validity of this immediate awareness. If it is accepted that the subjectively felt act of choice actually occurs, then this act is represented in the physical world, as represented by the wave function of quantum theory, as the choice of branch that physically initiates the subjectively chosen course of action. Further details may be found in Ref. [14].

6. Quantum Mechanical Conception of Man

The essence of man lies in his ability to make decisions that determine, in part, the course of the creative process. The quantum mechanical description of the human decision-making process distinguishes two aspects: the personal and the cosmic.

The personal aspect is represented by the von Neumann process 2: it generates patterns of brain activity in accordance with the physical laws of motion. This personal aspect is local and deterministic. It brings into the decision-making process the effects of the conditioning of the brain by genetic and environmental factors. The history of the individual, as embodied in the biological, physiological, and chemical structures represented in the wave function of the brain, controls the personal aspect. This aspect generates a wave function with different branches representing different alternative possible courses of action, each with an associated probability.

A reduction then occurs. Viewed from the perspective of physical theory this reduction is stochastic: it is a random process subject only to the statistical conditions specified by quantum theory. The reduction process is also nonlocal. It is related in a special way to the localized brain of the individual, for it selects a certain branch of the localized brain wave function. But this localized reduction entails an associated reduction of the wave packets of all particles with which the particles of the brain have interacted in the past. Thus the localized reduction generates associated reductions in far-flung parts of the universe. Bell's theorem [15] shows that these nonlocal changes have nonlocal physical ramifications: the course of observable events in far-away regions cannot always be independent of the choices associated with the localized region. Thus the process of reduction represents a nonlocal or cosmic element in the human decision-making process. With respect to the laws of physics this cosmic aspect of the decision-making process is indeterminant, or free.

Classical physics portrayed man as a puppet controlled by

the iron hand of a destiny ordained at the beginning of time. Man was thereby automatically relieved of all responsibility for his acts. In quantum theory the deterministic factors that bear on man's decisions, whether they arise from nature or nurture, merely create the potentialities for possible action: the decision as to which potentiality is actualized is not fixed by the deterministic laws of physics. Thus negation of personal responsibility is no longer the unavoidable logical consequence of accepting the scientific world view.

7. Chance, Determinism, and Freedom

Within the framework of physical theory (i.e., quantum theory) the process of selection associated with a reduction of a wave packet is stochastic: it involves an irreducible element of chance. The question thus arises whether this occurrence of chance in the theory reflects an element of chance in nature herself, or rather an incompleteness of the theory, if viewed as a representation of nature.

Freedom resolved by a play of chance, is, from a moral viewpoint, no better than no freedom at all. Yet absence of chance might seem tantamount to determinism, hence absence of freedom.

Quantum theory provides a way out of this dilemma: it provides a middle way between chance and determinism, the way of self-determination or freedom.

The normal concept of determinism reflects the idea that laws are prior to the actual world. The laws are timeless, whereas the actual world evolves.

According to the quantum mechanical conception of nature the actual is not selected initially, but rather evolves gradually, and in a nondeterministic way. Within this context it would be contradictory to assume that rules which determine the choice of the actual are fixed initially, hence prior to the undetermined actuality itself. For then the actuality would in fact be predetermined, by laws that are prior to the actual.

The most natural alternative is that conditions within the evolving actuality determine its evolution, and that these conditions cannot be formulated in terms of general laws that stand either above, outside, or prior to the actual: essence cannot precede existence.

This conceptualization reconciles Einstein's dictum that

"God does not play dice with the universe", with Bohr's contention that quantum theory is complete, in the sense that there are no physical laws lying deeper than the statistical laws of quantum theory. For the conditions that determine the evolution of the actual exist only within the global evolving actual situation itself, not in the form of general timeless laws.

8. Summary and Conclusions

Understanding the connection between mind and matter has been described by William James as "...the scientific achievement before which all past achievements would pale". This evaluation undoubtedly stems, at least in part, from the sheer impossibility of any natural connection between mind and matter in the framework of the classical physics of James' day. The difficulties were two-fold: the category problem and the causality problem. The first problem is that the categories of thought used to comprehend physical systems in classical physics were completely different from those used to comprehend thoughts. Physical systems were described by the positions and velocities of myriads of particles, with each whole system being nothing more than the collection of its parts. A conscious thought, on the other hand, was a holistic entity described in a completely different language. Though an *ad hoc* correspondence could be contemplated, there was no possibility of a natural correspondence in terms of the concepts involved.

The second problem was that thoughts appear to control bodily movements, but classical physics permits no agent of outside control: the flow of events in classical physics is the same whether a conscious thought occurs or not.

These problems dissolve when classical physics is replaced by quantum theory. For in quantum theory there is, in addition to the wave function, which represents the analog of the positions and velocities of all particles, also a second element, a sequence of acts. These acts are reductions of wave packets. If each conscious thought is interpreted as an act then each subjectively felt act can be identified with a physical act, and can be represented in physical theory by a corresponding act of reduction of the wave packet.

This resolution of the mind-body problem creates a quantum mechanical conception of man and his role in nature. He

is no longer a passive observer of the aftermath of a cataclysmic initial act of creation, but rather an active participant in the process of creation.

Two separate aspects of this participation are identified by quantum theory. The theory spells out in mathematical terms the nature of a local, deterministic, personal input while simultaneously demanding also a nonlocal, nonpredetermined cosmic input. Thus quantum theory defines man as a mathematically delineated blend of personal and cosmic elements.

This quantum mechanical conception of man is similar, in some respects, to ideas that are at least as old as the written philosophic records of man. What is new is the connection to science. Science in the form of classical physics has traditionally stood apart from ideas of this kind, and has, in fact, opposed them. The importance of quantum theory in this connection is not simply that it allows one to entertain ideas of this general kind, but rather that it actually leads directly to a relatively specific new conception. For once the decisive importance of quantum mechanical processes to the functioning of the brain is recognized, and the physiology and circuitry is worked out, it is, I think, assured that the process of reduction of the wave packet will be found to be important. This is a matter that scientific investigation can soon settle. von Neumann's analysis then shows that the place where the reduction occurs can be shifted from the microscopic level to the level of holistic macro patterns of excitation. The question is then whether to accept or reject the validity of our direct awareness that we can and do make decisions that influence the course of physical events. If the idea that we do make such choices is accepted then the nonlocal or cosmic character of the reduction process follows directly from Bell's Theorem. This produces a vision of man profoundly different from the one suggested by classical physics. This vision is not simply the product of intuitive insight, but emerges from a rational examination of the ramifications of quantum theory in brain dynamics.

This revised view of the nature of man should have a

profound, and even decisive, impact on the fate of man. For science has already given man the power to solve his major physical problems. The critical remaining problems lie in the sphere of the intellect. Here the dominant influence is the force of ideas. But a shift in the scientific conception of man from that of an isolated, accidental, mechanical epiphenomenon to that of cosmic agent of the creative power of the universe must inevitably deflate egocentric values and enhance the sense of harmonious enterprise with others, and with nature, in the creative unfoldment of new wonders.

REFERENCES

[1] Lester Ingber, *Physica* **5D** *(1982) 83-107*, and *Physical Review A* (to be published).

[2] Niels Bohr, *Atomic Theory and the Description of Nature* (Cambridge University Press, 1934), p. 20.

[3] *Ibid*, p. 21.

[4] *Ibid*, p. 22.

[5] H.P. Stapp, *Am. J. Phys.* **40** *(1982) 1098-1116.*

[6] W. Heisenberg, *Physics and Philosophy* (Harper Brothers, New York, 1958), p. 54.

[7] J. von Neumann, *The Mathematical Foundations of Quantum Theory* (Princeton University Press, Princeton, NJ, 1955) p. 418.

[8] E. Wigner, in *The Scientist Speculates*, I.J. Good, ed., (The Windmill Press, Kindswood, Surrey, England, 1962).

[9] Eric R. Kandel and James H. Schwartz, *Molecular Biology of Learning: Modulation of Transmitter Release, Science* **218** *(1982) 433-443.*

[10] J.C. Eccles, in *The Self and Its Brain* (Springer-Verlag, Berlin, 1978).

[11] R.W. Sperry, *Psych. Rev.* **76** *(1969) 532-536.*

[12] E.H. Walker, *Math. Biosciences* **7** *(1970) 131-178*, and *Intl. J. of Quantum Chemistry* **11** *(1977) 103-127.*

[13] H. Everett, III, *Rev. Mod. Phys.* **29** *(1957) 454-462*, and in *The Many Worlds Interpretation of Quantum Theory*, B. Dewitt and N. Graham, eds. (Princeton Univ. Press, Princeton, NJ, 1973).

[14] H.P. Stapp, *Fd. Phys.* **12** *(1982) 363-399;* **9** *(1979) 1-25.*

[15] J.S. Bell, *Physics (N.Y.)* **I**, *1964;* H.P. Stapp, *Phys. Rev.* **D3** *(1971) 1301-1320; Phys. Rev. Lett.* **49** *(1982) 1470-1474.*

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720