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Contemporary Models of Consciousness: Part I

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Recent models of consciousness are reviewed which explore the relationship of consciousness to physical laws; many of these also explore the relationship of consciousness to biological findings. Issues investigated by these models are discussed, with the issues framed in a general way in order to provide a comparison between the models. In Part I the issues discussed are: (1) What is the causal relationship between consciousness and the physical world (physicalism, dualism, etc.)? and (2) What physical characteristics are associated with the interface between brain/physical world and consciousness?

A number of models of consciousness have appeared in recent years which investigate the relationship of consciousness to the brain and the physical world. The models discussed here all have a physical orientation, in that they have addressed the question of what physical principles may be involved in the relationship of mind to the physical world, and many of them have also addressed biologically oriented questions about the relationship of mind to brain. The publications presenting these models have, in nearly all cases, appeared in the years from 1975 to 1990; in the case of a few models, publication has occurred over a number of years, commencing before 1975 (as early as 1963) and then continuing into the 1980's.

Parts I and II of this paper will review these models with respect to various physical and biological issues they have discussed, framing the issues in somewhat general terms so we can compare what different models have said. In Part II we will discuss the question of whether all the information content of conscious experience is defined in the brain; the possibility that consciousness can process information independently of the brain; and some other issues related to these questions. The issues to be discussed in Part I are as follows:

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1. What is the causal relationship between consciousness and the physical world (physicalism, dualism, etc.)?
2. What physical characteristics are associated with the interface between brain/physical world and consciousness?

This paper also serves the purpose of assembling references to these models, which are published in various books and journals in the physical sciences, the biological sciences, and other fields. A list of references for each model is given in Table 1.

Table 1

Contemporary Models of Consciousness

Author	*Type of Model*	*Physical Characteristics Associated with the Mind/Brain Interface*
Consciousness Generated from Brain/Physical World		
Culbertson (1963, 1976, 1977a, 1977b, 1982)	Physicalism	Consciousness associated with physical world at many points of space-time. Interconnections in brain determine subjective qualities
John (1976, 1980)	Physicalism	Electrochemical processes in complex, appropriately organized matter
Sperry (1965, 1969, 1976, 1977, 1983)	Mentalism (mind arises from brain, but can act causally on it)	New physical principle, hierarchically higher than present physical laws
Valentine (1982)	Physicalism	Quantum mechanical
Independence/Dependence of Consciousness on Physical World Not Specified in Model		
Bass (1975)	Not specified	Quantum mechanical (Wigner-von Neumann-type observer theory)
Bateson (1979)	Not specified	Aggregation of sufficiently complex parts, with circular chains of determination; action related to entropy
Jahn and Dunne (1986, 1987)	Not specified (model pertains to interface only, not to relationship between consciousness and its environment)	None specified; quantum mechanical concepts are used as a metaphor

Table 1—Continued

Contemporary Models of Consciousness

Author	*Type of Model*	*Physical Characteristics Associated with the Mind/Brain Interface*
Lövland (1981)	Not specified	Thermodynamic (related to energy)
Stapp (1982, 1985)	Not specified	Quantum mechanical (Heisenberg-type observer theory)
Zeeman (1976, 1977)	Not specified	Phenomena which have discontinuous changes in stable states (via catastrophe theory)
Consciousness and Physical World are Independent Realms Which Interact		
Burns (1981, 1986, 1990)	Dualism	Thermodynamic (related to entropy)
Eccles (1979, 1980, 1986); Eccles and Robinson (1984); Popper and Eccles (1977)	Dualism	Quantum mechanical
Kroon (1989, 1990)	Dualism (matter subordinate to Universal Mind)	None
Sirag (1988)	Dualism	Mind connects to physical world at all points of space-time—no special properties are needed. But interconnections in the brain may provide a greater complexity to conscious experience
Walker (1970, 1979, 1984, 1985); Mattuck and Walker (1979)	Pragmatic dualism	Quantum mechanical (Wigner-von Neumann-type observer theory)
Other Relationships		
Bohm (1982)	Implicate Order (mind and brain have no interaction; they derive from the Implicate Order and act synchronistically)	None (there is no brain-mind interface)

Table 1—Continued

Contemporary Models of Consciousness

Author	*Type of Model*	*Physical Characteristics Associated with the Mind/Brain Interface*
Goswami (1986, 1989, 1990)	Monistic idealism, with immanent brain-mind having a relationship of causal circularity to the quantum mechanical domain	Quantum mechanical (Heisenberg-type) observer theory)

Although we are discussing models which have a physical orientation, and which may also include biological issues, a comparable amount of research about consciousness has been published in other fields. Because not all of this work is well known, it may be helpful to mention these fields and cite some sources of the literature. Works by Edelman (1978), by Uttal (1978), and edited by Davidson and Davidson (1980) address an array of issues having a bearing on the mind-brain relationship. S. Walker (1983) and D. Griffin (1984) each investigate the possibility of consciousness in animals, and each author gives a listing of further references. Baars (1989) presents a theory of consciousness which is related to empirical findings in cognitive psychology; he includes references to other work relating consciousness to this body of data. Some of the physically oriented models discussed herein, in keeping with their multidisciplinary and exploratory nature, include consideration of the possible relationship of psi phenomena to consciousness; this aspect of the models is not discussed.

The works discussed herein are described as *models* or *theories*, with these terms defined as follows: a *model* is considered to be a presentation of various hypotheses, most of which could be made independently of the others, but which are assembled together to describe various aspects of an entity (in this case, consciousness). On the other hand, a *theory* is considered to be a presentation of relatively few independent hypotheses, with the theory built to some extent on the hypotheses. Because the various issues of Parts I and II can each be discussed independently of the others, the above works are usually described here as *models*. However, if an author refers to his/her own work as a theory, that term is also used. (The term *observer theory*, used to describe several models, is known in the literature and will be defined when it appears.)

Comparing the models, it is convenient to have some terminology which can help express the issues. The term *consciousness*, as used herein, refers to the total description of conscious experience, with all its attributes (whatever these may be), and the term *physical world* refers to the objective world. All of the models discussed consider consciousness to have some qualities, such as awareness or subjectivity, which are different from known qualities of the physical world. In this sense we can refer to consciousness and the physical world as different *realms*, which may have some qualities in common, but which also have some differences. The characterization of consciousness as a separate realm is not meant to have any implication regarding the causal relationship between consciousness and the physical world, however.

The models agree on very little, as we will see. However, the issues they explore are important in understanding the fundamental nature of consciousness, and the multiplicity of views they offer can bring a wider perspective to these issues.

The Causal Relationship Between Consciousness and the Physical World

Consciousness Generated from Brain/Physical World

Some models consider that consciousness arises from some special condition in the brain. Consciousness might derive from an extension of some presently known physical principles, such as quantum mechanics (Valentine, 1982). Or it could derive from some new pysical principle, not presently known, which is unique to the brain (John, 1976; Sperry, 1983). (We will discuss in the next section the specific physical principles proposed as a link between mind and brain/physical world.)

It is also possible that consciousness derives from the physical world and yet is not generated by the brain. Thus Culbertson (1963, 1976, 1977a, 1977b, 1982) proposes that consciousness resides at all points of space-time at which a scattering process takes place. He points out that it is through the scattering of light or sound, or other forms of scattering, that signals come from material objects to our bodies. He proposes that a "picture-making network" of interconnected neurons in the brain generates those aspects of conscious experience which are specific to an individual. However, the consciousness associated with these experiences is not produced by the brain, but resides in the space-time points at which scattering occurs.

We can describe the above ideas as *physicalism*, the view that consciousness derives from some principle or condition in the physical world, either through an extension of presently known principles or through some new principle, not previously known. We should note that Sperry (1965, 1969, 1976, 1983), who proposes that consciousness derives from the brain, calls his model *mentalism*. He uses this term because his model also specifies that consciousness can act independently of the brain, and this name serves to distinguish his model from physicalist theories in which consciousness is conceived to be purely passive.

Culbertson (1963, 1982), who also proposes independent processing, refers to his theory as physicalism, however.

Independence/Dependence of Consciousness on Physical World Not Specified in Model

A number of models do not make any statement regarding the independence or dependence of consciousness on the physical world (Table 1). Of these, Jahn and Dunne (1987, pp. 203—204) are explicit that no statement about this issue will be made. They propose that consciousness and its environment are domains which exist only as information, and that all of what we consider reality—whether physical objects or conscious experience—exists only at the interface between these domains. Thus they specify that their model pertains to this interface only.

Several other models (Bass, 1975; Bateson, 1979; Lövland, 1981; Stapp, 1982, 1985; Zeeman, 1976, 1977) make no statement about the independence or dependence of consciousness on the physical world. In these, there is extensive discussion of physical principles, so that the impression is easily conveyed that they are models of physicalism. Although various non-physicalist models have appeared in recent years, it is probably true that a large number of researchers in Western science favor the basic idea of physicalism. So, for any of the above models, it may be that the author has simply taken for granted the idea that consciousness derives from the physical world. Or it may be that he or she did not wish to address the issue. In the absence of any specific statement, we have no way of knowing.

Consciousness and Physical World are Independent Realms Which Interact

Another possibility is that consciousness and the physical world are independent realms which interact; this view can be described as *dualism*. It is important to realize, however, that there are several types of realm involved in the models discussed herein, and that the combinations used vary from model to model. Let us call the physical world Realm 1, and call the aggregate of all possible conscious experience Realm 2. We can describe Realm 3 as spaceless, timeless and incapable of division; the experience of Voidness or pure consciousness discussed in mystical philosophy is often described as having the latter attributes. Eccles proposes that human knowledge and culture comprise a realm separate and different from Realms 1 and 2, which we can call Realm 4 (Eccles, 1979, 1980; Eccles and Robinson, 1984; Popper and Eccles, 1977); however, no other model proposes this. Table 2 gives a summary of terms the models (dualistic or otherwise) have used for these realms.

Kroon (1989, 1990) discusses Realm 1 and Realm 3 only. On the other hand, Burns (1981) refers to all three realms, although her model is primarily focused on Realm 2. Because ordinary conscious experience changes, and change is a

Table 2

Terms Used to Describe the Realms in Models of Consciousness

Realm	*Other Terms Used*
Realm 1 (the physical world)	**World 1** (Eccles, 1979; 1980; Eccles and Robinson, 1984; Popper and Eccles, 1977)
1a:	the "classical" world which follows ordinary descriptions (see discussion of Heisenberg-type observer theories)
1b:	the quantum world, in which the state of a system may be expressed in terms of mutually exclusive possibilities (see discussion of Heisenberg-type observer theories)
Realm 2 (the aggregate of all possible conscious experience)	**differentiated consciousness** (Burns, 1981) **Mind** (Sirag, 1988) **subtle world** (Goswami, 1989) **World 2** (Eccles, 1979, 1980; Eccles and Robinson, 1984; Popper and Eccles, 1977) **mind, consciousness**—terms often used in the models to refer to the aggregate of all conscious experience (without necessarily implying that Realm 2 is independent of Realm 1)
Realm 3 (spaceless, timeless, incapable of division)	**consciousness** (Goswami, 1989, 1990) **Implicate Order** (Bohm, 1982) **Mind, Universal Mind** (Kroon, 1989, 1990) **pure consciousness, undifferentiated consciousness** (Burns, 1981)
Realm 4 (human knowledge and culture)	**World 3** (Eccles, 1979, 1980; Eccles and Robinson, 1984; Popper and Eccles, 1977)

characteristic of time, Burns makes a distinction between Realm 2 and Realm 3, which is timeless, on this ground. The only other models to refer to Realm 3 are those of Bohm (1982) and Goswami (1989, 1990), as we will see shortly.

Because Realms 1 and 2 have somewhat different descriptions, and therefore somewhat different properties, we can ask what the properties of Realm 2 are. The models of Burns (1981, 1986) and Sirag (1988) each make proposals about the nature of these properties. Burns makes a contrast between the subjective nature of conscious experience and the objective existence of the physical world, which can be described independently of any given observer. She considers subjectivity—the fact that conscious experience is subjective—to be a property of Realm 2, and suggests that the objective space and time of the physical world are not properties of Realm 2.

Sirag's (1988) theory describes the properties of Realms 1 and 2 from a different point of view. Sirag starts from the context of a unified field theory he has developed in which the physical world is described by a mathematical space which has certain properties (the basic symmetry properties of the physical world). He points out that the mathematical space corresponding to the physical world can be linked to another mathematical space which has different properties. Because the first space is considered by the theory to encompass the physical world (Realm 1), the second space must be something different, i.e., non-physical. He proposes that the second space comprises all potential conscious experience (Realm 2), and that the intersection of the spaces (the portion common to both) describes conscious experience itself.

The mathematical properties of the intersection thus can tell us what Realm 2 and the physical world have in common, and the full properties of the second space can tell us the properties of Realm 2 which are different from the physical world. The intersection has the property of time, but not physical space, consistent with the fact that conscious experience does not occupy physical space. The difficulty in describing the full properties of Realm 2 is that we do not initially know which qualities of conscious experience correspond to which mathematical properties. However, Sirag has made an initial suggestion that the "reflection properties" of this space correspond to our conscious ability to reflect, and other possible linkages between this space and conscious experience could be explored.

Other dualistic models do not explore the properties of consciousness to any great extent. In fact, Walker (1985) characterizes his model as *pragmatic dualism,* in which consciousness is considered to be independent of the physical world for the purpose of studying it, but in which the dualistic aspect of the model could be rescinded later if desired.

A great deal of empirical evidence shows that conscious experience can be affected through brain injury, electrical stimulation of cortex, or other means of affecting the brain (Blakemore, 1977). Thus it would seem that there must be some interaction between consciousness and the physical world; but if these realms have different properties, how can they interact? Several models (Burns, 1986; Eccles, 1980; Sirag, 1988) address this question. Sirag's (1988) theory describes Realms 1 and 2 as mathematical spaces which have a common intersection; thus the "interaction" could be described as the action of the common elements. Burns (1986) proposes that mind can identify with or "borrow" properties from the physical world, a capability she calls the "principle of identification." She likens the action of this principle to pouring water in a pitcher—the water retains its own properties, yet takes on the shape of the pitcher; similarly, mind may retain its own properties, yet be able to follow physical actions of the brain. Eccles (1979, 1980; Eccles and Robinson, 1984) characterizes the interaction in terms of a flow of information, with information a quality common to both realms.

Other Relationships

It is possible that there is no interaction, causal or otherwise, between mind (Realm 2) and the physical world (Realm 1), and Bohm (1982) makes this postulate. He proposes that both mind and the physical world derive from another entity, the Implicate Order, which he describes as an unbroken whole, from which time and space emerge (Realm 3). He explains the apparent dependence between mind and brain by proposing that they act synchronistically, because of their joint origin (p. 209).

Bohm points out that our explicit mental experience (Realm 2) occurs with an implicit content in the background—in a piece of music this is the part that has gone before, without which individual notes would have little meaning, and in general this would be the context experienced for that situation. He considers this implicit content to be part of the Implicate Order (p. 209).

The model of Goswami (1986, 1989, 1990) offers yet another possibility. Goswami (1989) considers Realm la, the material world, and Realm 1b, the quantum mechanical world of possibilities, to be ontologically separate domains (see next section for discussion of quantum mechanical issues). In this model the material world (Realm la) and mental phenomena (Realm 2) both arise out of Realm 1b, which is a domain of transcendent archetypes. In this respect the model is described in terms of three realms (1a, 1b and 2); however, this is a model of monistic idealism, in which consciousness is the basic reality that encompasses all else. Goswami draws on a metaphor of Plato to express this idea—"consciousness" is a light which shines on the archetypes and casts a shadow—their manifestation. Goswami (1989, 1990) describes consciousness as being outside space and time, and because he links his model to mystical philosophy, the qualities of "consciousness" are presumably akin to those of Realm 3, although he is not specific about this point.

Goswami (1989) further considers that the mind-brain aspect of Realms la and 2 is necessary for these realms as a whole to arise out of the realm of archetypes (Realm 1b), and thus he holds that mind-brain and the quantum realm have a relationship of causal circularity. Goswami (1986, 1990) suggests that the mind-brain system is self-organizing (autopoietic) with a "tangled hierarchy," and that this tangled hierarchy produces the circular causal chain.

Physical Characteristics Associated with the Interface Between Brain/Physical World and Consciousness

Kroon's (1989, 1990) model, which postulates a relationship between Realms 1 and 3, holds that it is not possible to know anything about the physical nature of the brain-mind interface. And Bohm's (1982) model of the Implicate Order claims that there is no brain-mind interface, as we have seen.

Aside from this, all the models we are considering here make a proposal regarding the nature of this interface. However, it is important to realize that the interpretation of the interface would vary with the type of model. In a physicalist or mentalist model, the interface would be regarded as causative, and would generate consciousness. On the other hand, in dualism the interface would be regarded as mediating between two realms. In each model, we can speak of the physical principles or conditions associated with an interface, keeping in mind that the interpretation of the interface depends on the model.

Complexity and Hierarchical Principles

Two models propose that sufficient complexity, as in the brain, might be able to generate consciousness. Bateson (1979) proposes that the interface is involved with an aggregation of sufficiently complex parts, with circular chains of causation. And John (1976) suggests that the interface is involved with electrochemical processes in complex, appropriately organized matter. As Walker (1985) has pointed out, most brain processing takes place on an unconscious level, with only a small part being conscious; therefore, any "complexity theory" would have to explain why only a portion of this processing becomes conscious. However, the above models have not discussed this issue.

Sperry (1965, 1969, 1976, 1983) also proposes that consciousness is produced by a new principle, not presently known to physics. He points out that electrochemical interactions take place independently of interactions in the mucleii of atoms, and characterizes the former as "hierarchically higher" than the latter. In the same way, he proposes, another principle may exist, hierarchically higher than electrochemical interactions, which produces consciousness. Sperry (1977) points out that in split brain patients, for whom each brain hemisphere no longer has access to information in the other hemisphere, all evidence indicates that conscious experience is no longer a unified product of both hemispheres; thus intact connections between regions of the brain are evidently needed for unified experience to be produced.

Consciousness Associated with All, or Many, Events in Space-Time

In Sirag's (1988) model consciousness is associated with every point in space-time. However, he suggests that the content of consciousness associated with a brain may have a greater complexity because of the many interconnections of the brain.

In Culbertson's (1976, 1977a, 1977b, 1982) model, not all points of space-time are conscious; rather, it is those points of space-time through which a photon traces a scattering path which satisfies some simple conditions. The space-time path of sound waves and other types of scattering can also satisfy these conditions; thus consciousness can be associated with not only visual experience, but other sensory modalities also (1982, p. 6). What is consciously perceived is the space-time point where the scattering occurred, and this aspect of consciousness is generated at that point, not in the brain. However, various subjective qualities, such as color, are produced by special "picture-making" interconnections in the brain; these neural connections are considered to be different from the ones used in ordinary brain processing.

Culbertson (1982) accounts for the conscious experience of memory through an electromagnetic interaction of zero space-time length, which is confined to a single neuron. Although photons have a space-time path of null length because they travel at the speed of light, a localized electromagnetic interaction would not ordinarily have a null-length path. Thus the above interaction is not part of present physical theory, and must be considered a new proposal.

Quantum Mechanics—Observer Theories

Four of the models can be called observer theories; this name derives from a proposal which can be made regarding an unresolved issue underlying quantum mechanics. The issue is that we experience the physical world in terms of definite events, but quantum mechanics describes the physical world as being inherently in a combination of different states, with each state having a probability assigned to it. As an example, let us suppose that your house could be demolished by some catastrophe which is looming. For simplicity, we will assume that the catastrophe will either demolish the house or leave it completely intact. Then quantum mechanically, the house could be described as 50% in the demoloshed state and 50% in the completely intact state, a description which makes no sense in terms of ordinary experience. This discrepancy between ordinary experience and quantum mechanical description has no explanation in terms of any principles presently known to physics.[1] Various "interpretations" of quantum mechanics have been made to account for this discrepancy; one of the best known is the "Copenhagen interpretation," which states that quantum mechanics is simply an abstract description that needs no explanation (Herbert, 1985). However, many other interpretations exist, and among these is the observer theory, which proposes that a conscious observer is needed for the collapse of the probabilistic description (the quantum mechanical wave function) to a definite state (Herbert, 1985).[2]

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[1]This underlying problem is sometimes thought to derive from the Heisenberg uncertainty principle, but this is not a correct statement. Quantum mechanical description is specified in terms of a wave function which can determine the probabilities of mutually exclusive events. All wave phenomena have certain innate characteristics, and the uncertainty principle is a statement of these characteristics (Herbert, 1985, Chapters 5, 6). The problem is that our experience of the physical world is composed of definite events, not contradictory possibilities.

[2]In some interpretations of quantum mechanics (e.g., Heisenberg, 1958, p. 54) an act of "measurement" collapses the wave function. However, in the four models cited here, the presence of an observer is sufficient to produce collapse, without any special act of "measurement."

To understand the differences between the observer theories discussed here, we should know about two of the interpretations of quantum mechanics, the Heisenberg interpretation and the Wigner-von Neumann interpretation. In the Heisenberg interpretation the physical world can be described in terms of two domains, Realms 1a and 1b, which are ontologically different; Realm 1a contains ordinary objects, like your house, and Realm 1b contains these things in potential, or possibility, form only. Some means are needed by which the potentialities become actualities; this could take place via an observer and/or some other means.

The models of Stapp (1982, 1985) and Goswami (1989, 1990) each propose that the physical world and the quantum mechanical world are ontologically different realms, and thus can be described as following the Heisenberg view. Goswami does not propose any method of collapsing the wave function except through an observer. Stapp considers that collapse can take place not only through an observer, but also by some creative agency which continuously operates in the universe.

In the interpretation put forth by Wigner and von Neumann, no mention is made of separate realms. Thus objects presumably exist in only one domain, but they can follow different types of description in that domain. An object is described by the multiple possibilities of a quantum mechanical wave function until an observer is present; one of the possibilities can be selected out through the presence of the observer. Bass (1975) and Walker (1979, 1984, 1985; Mattuck and Walker, 1979) follow this interpretation.

Thus, although the models discussed here agree that an observer is associated with collapse of the wave function, they do not all agree in their interpretation of quantum mechanics; it is important to realize that observer theories may differ in this regard. Each of the models addresses the question of how the conscious observer is related to the brain, and they do have some agreement regarding this point. Each model proposes that the brain (or a neural net in the brain) can be characterized by an overall quantum mechanical state, with collapse of the wave function taking place through the presence of the observer. Choice (free will) determines the brain state which results from collapse, and thereby determines individual action.

Here we should finally note a further difference between the observer theories. Walker (1979, 1984, 1985; Mattuck and Walker, 1979) considers that the *only* way that wave function collapse can occur is through consciousness. Consistent with this view, he specifies that the presence of consciousness not only determines the brain state of an individual, but also external reality, and that if several people jointly observe something, they jointly create external reality (Walker, 1985). Goswami (1989, 1990) also suggests that only consciousness can collapse the wave function. However, Goswami specifies that consciousness is transcendental in nature and not limited to individual observers, so wave function collapse can occur even when no individuals are present. Aside from Walker's model, none of the observer theories suggest that collapse of the wave function in the brain does anything more than select a brain state to carry out individual action. It must be said that Walker's proposal that the external world is created by its joint observers represents an unusual view. On the other hand, if consciousness is not the only way to collapse the wave function, then we are left with the question of how this collapse is accomplished outside the brain.

Bass (1975) models the way in which a wave function might act on an ionic channel in a synapse, in order to investigate how wave function collapse could lead to nerve cell excitation, and thereby to selection of an action. He shows that wave function collapse could produce activation of an ionic channel, but notes that some 10^2 channels are usually involved in nerve cell excitation. However, Bass points out that specialized neurons which can respond to activation of only one channel might have been developed in evolution to facilitate the use of volition.

Regarding the idea that the brain could be described by an overall quantum state, it is of interest that Stuart, Takahashi, and Umezawa (1979) explore the idea that memory might take place by means of such an overall state. Also, Woo (1981) discusses possible empirical tests of whether the brain is described by an overall quantum state.

Quantum Mechanics—Non-Observer Models and Aspects of Models

Several non-observer models—those of Eccles (1986), Jahn and Dunne (1986, 1987) and Valentine (1982)—also propose that the interface between mind and the physical world is especially connected with quantum mechanics. Each of these authors, and also Walker (1979), who has an observer model, discuss specific mechanisms by which the interaction between mind and brain/physical world might take place.

Considering these models, we should realize that they describe different aspects of the interface. Walker and Valentine each consider consciousness in its aspect of reflecting information which is encoded in the brain. It is well known that the amount of information in conscious experience is far less than the amount which is processed in the brain, and the above authors propose a mechanism to account for this discrepancy, as we will see. On the other hand, the models of Eccles and of Jahn and Dunne focus on a process going the other way—the influence of mind on brain—and they suggest mechanisms by which this influence may be produced.

Valentine (1982) proposes that a quantum mechanical mind-brain interaction takes place by means of electrical synapses. He points out that chemical synapses, the type which emit transmitter vesicles, are typically 200 nm wide, too far readily to allow electron tunneling. However, a minority of vertebrate synapses are quite narrow, about 2 nm, and transfer electric potential directly. Valentine points out that the latter distance allows electron tunneling, which provides a possible mechanism through which parts of the brain that are involved in active processing at any given time could be linked into a single quantum mechanical system. This mechanism could account for the unified nature of experience. Because electrical synapses are relatively rare, it could also account for the discrepancy between the amount of information in conscious experience and the amount processed by the brain.

E.H. Walker (1977) proposes that a nerve impulse can cross a synapse in the brain by electron tunneling, and he (1970, 1979) links consciousness to electron tunneling. In this model the arrival of an action potential produces electron tunneling across the synapse gap, and this in turn causes conformational changes in macromolecules at the vesicle gates, which cause the gates to open. However, in this model, transmission of information across a synapse is only associated with unconscious brain processing. Consciousness is associated with the relatively rare effect of tunneling, not directly across the gap, but to activated synapses at a distance, and hence the discrepancy between the amount of information in conscious experience and that processed by the brain is accounted for.

Eccles (1986) also suggests that the mind-brain interface may be especially involved with the transmission of nerve impulses across synapses. It is known that a neural impulse can be transmitted across the gap of a chemical synapse by vesicles of transmitter substance, and these vesicles are known to be emitted in a somewhat random way. Eccles proposes that mind can affect the probability of vesicle emission and in this way alter the flow of neural impulses, and he further proposes that this alteration of probability takes place via some quantum mechanical mechanism.

Jahn and Dunne (1987, p. 312) similarly propose that consciousness acts on the physical world through changing the probabilities of statistical processes, rather than acting on physical objects per se. And Jahn and Dunne (1986, 1987) also propose that quantum mechanics is especially involved with the interface between mind and the physical world. Their model is metaphorical, in that they suggest that laws of the physical world are concepts used by consciousness to describe its environment and as such can also reflect characteristics of consciousness itself. They note that such an approach could be applied to any concepts of human knowledge (Jahn and Dunne, 1987, p. 207). However, their emphasis is on quantum mechanics, and all their metaphors are from that field.

Cooperative Processes

John (1976, 1980) and Zeeman (1976, 1977) each explore the possibility that consciousness is associated with the cooperative action of many individual neurons, John from the standpoint of empirical data and Zeeman from a theoretical standpoint. John points out that the content of conscious experience has only a statistical relationship to the activity of individual neurons, with the empirical findings involved as follows: after presentation of a stimulus the firing of cells in a sensory processing area can be described in terms of an initial stage (up to about 60 msec) and a later stage (> 60 msec). Measurements show that, during the initial stage after a stimulus, the evoked potential, reflecting the aggregate action of individual neurons, will show a pattern typical for that stimulus. This stage of the evoked potential is called *exogenous,* and John refers to the stimulus-specific aspect of conscious experience associated with this stage as *sensation.* During the later stage, components of the evoked potential are known to be related to associations, memories and behavior elicited by the stimulus, rather than specific to the stimulus itself. For instance, sensory stimuli which are the same, but have different meanings—such as a vertical line which represents either the numeral "1" or the letter "I"—produce different evoked potentials at about 170 msec after the stimulus; but stimuli which are different, but have the same meaning—such as small letters and capital letters—produce the same evoked potential at this time (Grinberg-Zylberbaum and John, 1981). This stage of the evoked potential is called *endogenous,* and John refers to the aspect of conscious experience associated with this stage as *perception.*

Because the evoked potentials reflect the aggregate action of many neurons, one might suppose that individual neurons could be found whose activity would show a correspondence with the endogenous potential; the activity of such neurons could then be considered encoding for the content of perceptual experience. Measurements show that the activity of many neurons is stimulus-specific even at the endogenous stage; however, a significant proportion of neurons (about 1/3 in visual cortex) have activity which can be shown to be specific to the endogenous interpretation of the stimulus. The activity of cells in the latter population is highly variable, and it is only when the response of a cell is averaged over a number of events with a given endogenous interpretation that such a relationship is demonstrated. Nevertheless, cells in the latter population which are at different locations can show average activity, for a given endogenous interpretation, which is very similar (Ramos, Schwartz, and John, 1976a, 1976b).

If the activity of neurons associated with interpretative information is highly variable, then it does not appear that the encoding of this information is done at the level of individual cells. Rather, given the facts that a) the aggregate action, as represented by the evoked potential, shows a consistent pattern for a given endogenous interpretation; and b) the average action of a given cell, for events with the same endogenous interpretation, shows a consistent pattern, it appears that interpretative information is encoded in the brain as some sort of aggregate action of many cells. After reviewing this data and noting that stimulus-specific neurons also produce variable responses, John (1976, 1980) postulates that conscious experience is associated with a cooperative electrochemical process.

Zeeman (1977, Chapters 8, 9) points out that neurons in an anatomical region of the brain can be linked via states in which oscillations take place over the entire region; because of the large number of neurons involved, there would be a very large number of resonant modes in each region. Zeeman proposes that information can be represented in the brain by the excitation of such a resonant mode; information represented in this way would thus be encoded by the cooperative action of many neurons rather than by the action of any specific individual cells. Zeeman also specifies that conscious experience which reflects this information would be associated with the resonant modes involved. Under this hypothesis, evoked potentials would be considered artifacts which are produced by the excitation of these electrochemical states.

Zeeman shows, through mathematical considerations, that the simultaneous activation of two resonant states, representing two simultaneous experiences, can result in a linking of these states, so that a later occurrence of one of these experiences tends to activate the resonant mode corresponding to the other; thus association is accounted for in this theory.

Zeeman (1976, 1977, chapter 1) points out that affects and drives, as shown by behavior in humans and animals, can change abruptly when circumstances in the environment show cumulative but only gradual change. For that reason Zeeman uses non-linear oscillators, which can move abruptly from one state to another with only a small change in a controlling parameter, in his model of resonant states in the brain. Zeeman also points out that catastrophe theory, a branch of mathematics which deals with abrupt changes, can be useful in describing such transitions. For instance, Zeeman shows that catastrophe theory branch of mathematics which deals with abrupt changes, can be useful in describing such transitions. For instance, Zeeman shows that catastrophe theory can model the behavior of a dog in the face of a gradually increasing threat; the dog will continue an attack up to a certain point, but then suddenly cease the attack and run. Zeeman also uses catastrophe theory to model abrupt behavior change in humans, such as in the cycle of obsessive fasting and uncontrolled gorging in bulimic individuals.

Thermodynamics

Burns (1986) points out that if consciousness can process information independently of the brain, this constitutes a violation of the second law of thermodynamics (see Part II forthcoming). Because the second law describes the change of entropy in processes of the physical world, Burns suggests that the brain-mind interface is related to entropy. Bateson (1979) also suggests that the brain-mind connection is related to entropy, although he does not elaborate on this point.

Lövland (1981) presents a metaphoric model in which various aspects of conscious experience are described by quantities which are analogous to, but not the same as, physical thermodynamics quantities. He considers that the mind-brain interface is associated with physical thermodynamic quantities, such as energy, and with the transfer of "facts" (i.e., information) from one realm to another.

Summary and Discussion

The issue of how consciousness relates to the laws of the physical world and, more specifically, to the brain is among the great questions of this century. The models agree on very little, and it would seem that this is a time for questions, rather than answers.

Consciousness and the physical world can be described as realms, or entities, which appear to have properties in common, but have some properties that are different. This fact, in and of itself, has no necessary implication for the causal relationship between these realms. However, a number of hypotheses have been made about the causal relationship between these: that consciousness emerges from the physical world (physicalism/mentalism); that consciousness and the physical world exist independently (dualism); that they have a relationship of causal circularity; and that they have no causal relationship to each other, but act synchronistically.

However, if we are to hope to develop some means of making an objective evaluation of an hypothesis, we should be able to specify some connection between the issue involved and empirical findings. Although other issues discussed by the models have been related to findings in physical or biological science, the question of causality has had no strong relationship to any empirical findings. Positions on this question seem to provide a framework for many researchers on which they can base their explorations. On the other hand, a number of researchers make no statement about the issue of causality in their model, and probably some of these hold no view on this question; in any case, it would appear to be possible to develop a model without taking any stand on the issue of the causal relationship between the realms. This issue seems at present to be basically a philosophical question.

Inquiring about the physical aspects of the interface between the realms seems more productive. The interpretation of the interface would vary according to one's view of whether consciousness "emerges" from, or is merely linked to, the physical world via the interface; these are differences which have to do with a presently unanswerable philosophical question. (And, of course, it may be true, as some models hold, that there are no physical aspects, or that it is not possible to investigate them.) Nevertheless, hypotheses about the physical aspect of the interface can be made more specific by relating them to empirical findings about the brain, or asking to what non-brain physical systems the hypotheses might also apply. As hypotheses are extended to include more data, one is better able to determine if they seem attractive.

Thus all the observer theories have proposed that the interface is associated with an overall quantum mechanical wave function in the brain, and several of the works described herein have explored what neurobiological characteristics the brain might have in such case. In a similar vein, several models have proposed that a new physical principle, associated with complexity, may mediate the interface; one can ask what other physical systems have a large number of interconnections, or might otherwise qualify as being "complex." Similar questions could be asked about other interface hypotheses; the above are meant to illustrate that point.

Since it is the qualities which are common to consciousness and the physical world which are presumably involved with the interface, asking what qualities are common to these realms can also be a way to explore the nature of the interface. The content of conscious experience is known to show a dependence on the brain, although this content is expressed in qualities unique to consciousness. Thus it can be useful to explore the role information may play in the interface, as several models have done.

Although consciousness and the physical world appear to have some qualities in common, it is not necessarily true that these realms have no differences, or trivial differences, between them. Part II of this paper will explore issues related to properties of consciousness which may be different from those of the physical world.

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