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Towards a Physics of Consciousness

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Parallels exist between the quantum mechanical behaviour of electrons in solids and the characteristics of consciousness. For example, similarly to the non-localisation of electrons in a crystal, consciousness at any instant spans all of its current contents and, just as electronic events within separate quantum systems are independent of each other, so the consciousness of each individual is private to himself.

Various physiological and biophysical mechanisms have, in the past, been suggested or discovered which might conceivably permit the formation of a unified quantum system in the sensory brain.

If conscious events are quantal events taking place in an extended system, the implication of the time-energy uncertainty principle is that they are always in transition and that the specious present is extended in time. This extension is necessary for the awareness of movement or change and for the ordering of movements into a biography.

The existence of different sensory qualities makes reasonable certain hypotheses about the topological nature of the sensory neural circuitry which is the locus of the above quantal events.

1. INTRODUCTION

The areas of physics known as Optics and Acoustics serve as a reminder that the entire subject has as its raw material human observations. Pearson (1937) claimed that physical laws merely provide brief conceptual formulae that summarise the routine of human perception and, in agreement with him, Einstein (1922) stated that the subject matter of all natural science consists of such sense-perceptions as are common to different individuals and which, therefore, are to some degree impersonal. Although it is true that more recently developed areas, such as electricity, seem often to deal with imperceptibles, it remains the case as Schrödinger (1950) pointed out that all information, however many ingenious devices have been used to facilitate the labour, goes back to the sense perceptions of some living observer. Thus, the physical world (or whatever it is whose effects upon the observer are described by Pearson's "conceptual formulae") is a distillation from sensation. Now, the available evidence suggests that the

totality of a person's sensations forms his consciousness, without residue. It can therefore be seen that the endeavour to give a physical account of consciousness is an exercise in mapping the characteristics of sensation itself onto the abstract conceptualisations which science has derived from the contents of sensation. (This distinction between sensation and its contents might offend a philosopher, but, on a practical level, it corresponds to two different questions which an observer, on seeing some object, might ask. On the one hand, he might ask, "What kind of external (i.e. conceptual) object would produce this sensation?" In this case he is thinking about the content of his sensation. On the other hand, the observer might ask, "What kind of intraneural activity (just as conceptual as the external object) could correspond to this sensation?" In this case, he is thinking about the sensation itself.)

Physics may conceivably be dependent upon consciousness for more than its subject matter, however. Thus the actual numerical values of physical constants may depend upon the fact that, had they had any other values, the universe would have developed in ways inimical to the evolution of life and thus of consciousness. This so-called Anthropic Principle is reviewed by Carr and Rees (1979). If, as has been held on the basis of this principle, there is a multiplicity of worlds with varying values for the physical constants (Everitt, 1973) and only in some of which is consciousness possible, then the interdependence between physical results and consciousness becomes strong indeed. Yet we may ask what it is about the physics of this particular world that allows consciousness to behave as it does.

2. UNITY AND SEPARATENESS

The formulae of physics are taken to describe the behaviour even of unobserved entities, which is to say that the observer is (reasonably (Ayer, 1956)) assumed only to form part of the physical world and to be one of many observers. If this is the case, then we are faced with Schrödinger's "Arithmetic Paradox" (1967). In its first form, this asks how it is that, despite the existence of many observers, only one mind is ever experienced. If all these observers form part of the same physical world, why is it that "plural mind" is never observed? If a physical account is to be given of consciousness some way must be found in which the physical world divides up into islands corresponding to the way in which each observer's consciousness is private to himself.

The second form of Schrödinger's paradox is, in some way, the obverse of the first and asks how the different senses, each with its own demarcated area in the brain, can be integrated in the consciousness of a single observer. Worse still, each component neuron of the sensory system is, in Sherrington's (1940) words, a unit-life centred on itself and each human unit-life, or consciousness,

consists utterly of the cell unit-lives. What is it about this aggregate of observably separate organisms that enables them to form a single mind?

In brief, if the world in all its detail forms a unity, why does consciousness not encompass the whole of the world? On the other hand, if the world is subdivisible into separate islands of identity how are brain cell lives, which under the microscope appear as insular as separate people, to coalesce into single minds? If physics is to help here, there must be physical principles which enable disparate details to be in some sense identified with each other, to form part of an indivisible whole, in some circumstances but not in others. Such principles, if applicable to nervous systems, would account for why each observer's experience consists of his vision, audition, tactile sense etc. and never consists (as conceivably it might) of a large number of for example different visual scenes.

3. QUANTUM MECHANICS AND CONSCIOUSNESS: SOME PARALLELS

Since neural activity is largely electrical in nature it might be expected that the required physical principles would be found in quantum mechanics, according to which particles of all kinds, including electrons, must be described as wavelike entities. The behaviour of electrons, on this theory, has curious and even paradoxical properties which seem to resemble closely the properties of consciousness. A hint at how to construct whole systems whose parts are to form an indivisible whole is given by the fact that electrons, in Schrödinger's words, "are not individuals". It is not possible, that is, to identify a particular electron. This is shown by the fact that electrons obey Pauli's "exclusion principle" (or alternatively behave according to Fermi-Dirac statistics) when they are in the bound state as, for example, when confined to the "potential well" surrounding an atomic nucleus. Schrödinger (1950) gives the following example. Suppose that in some such confined system there are two electrons and three energy states (corresponding to different degrees of agitation of the electronic wavefunction) that they may occupy. Then, if the electrons were identifiable individuals, their possible distributions over the states would be the classical (Maxwell-Boltzmann) one shown in Figure 1. (Many atoms and molecules behave like this.)

If, however, the particles were indistinguishable, but more than one could occupy a state, they would have the Bose-Einstein distributions of Figure 2.

Finally, if the particles were in principle indistinguishable and lacking individuality, they would have the Fermi-Dirac distributions of Figure 3.

The behaviour of electrons is as in Figure 3 and it is for this reason that Schrödinger said they were not individuals. Leighton (1959) went further and supposed that all electrons might be the same electron in a multitude of places at the same time. However, it is to be noted that the exclusion principle whereby

		Assignments								
		1	2	3	4	5	6	7	8	9
State	1	AB	A	A	B			B		
	2		B		A	AB	A		B	
	3			B			B	A	A	AB

FIGURE 1 Ways of assigning two non-identical particles (A and B) to three states. There are nine of these.

		Assignments					
		1	2	3	4	5	6
State	1	AA	A	A			
	2		A		AA	A	
	3			A		A	AA

FIGURE 2 Ways of assigning two identical particles to three states. There are six of these.

		Assignments		
		1	2	3
State	1	A	A	
	2	A		A
	3		A	A

FIGURE 3 Ways of assigning two indistinguishable, non-individual particles to three states. There are three of these.

the states of Figure 3 may not be multi-occupied and from which the non-individuality of electrons is deduced, can only be seen to operate when electrons are in the bound state. This is so because it is only in such states that the requirement that an integral number of electron wavelengths shall fit the orbit restricts the successive energy levels to discrete values corresponding to 1, 2, 3 etc. wavelengths. Beyond the maximum energy level, the electron has enough energy to escape "to infinity" from the confining potential well and because infinity has no endpoints there are no restrictions on wavelength and therefore on allowable energy levels. States in this region are therefore the "continuum states". Since these may take arbitrarily close values, there is no sense in which two electrons *could* occupy *exactly* the same state. It would be wiser, therefore, to restrict Leighton's statement to the circumstances from which the only available evidence comes and to assert that all electrons in a system like that of Figure 3 are the same electron. The discreteness which is thus essential to the non-individuality argument, entails that in the systems with which we are concerned energy may only be taken up or lost in quantal packets. They will hereafter be referred to as quantum systems. Such systems are found not only in atoms and molecules but also in metals and crystals of arbitrary size. In these a lattice of atomic nuclei forms an elaborate potential well, in which the behaviour of at least some of the electrons can be described as a complicated wave function spreading throughout the material with local maxima at the atomic nuclei. This wave function, which gives the probability of finding an electron at each point in the crystal, describes a single indivisible entity, for none of its electrons can be regarded as associated with any particular nucleus and they cannot be counted.

There is an obvious resemblance between this state of affairs and that of Sherrington's "single mind" arising out of the lives of its component neurons. for in the one case we find a number of indistinguishable electrons, each originally (before the formation of the crystal) confined to its own atom, now equally likely at all times to be found in the vicinity of any nucleus in the crystal and in the other case we find a host of separate details, each mediated by different brain structures and cell systems, but all somehow belonging to a single observer, as if the observer is at each time paradoxically in the presence of all the details of his observation. Thus we seem to have the possibility that some of the counter-intuitive discoveries of recent physical science can be used to account for some of the corresponding aspects of consciousness that are puzzling on the basis either of the classical physics of discrete entities or of the intuitive view of the world as made up of "objects". In particular, there seems to be a possible physical resolution of Schrödinger's second Arithmetic Paradox. More attention will be given to the details of this in a later section. For the present, the first Arithmetic Paradox must be reconsidered.

The world may be conceived, as far as electrons are concerned, as being made

up of a number of isolated potential wells (the regions close to atomic nuclei etc.) each containing a number of trapped electrons which form a quantum system. It is not an arbitrary decision where to set the limits of such a system, for a system is isolated if the electronic states within it are independent of changes in state of other neighbouring systems. Thus, in certain gases, any given atom may be excited into a given state regardless of the states of surrounding atoms. If it is a many-electron atom it is impossible, for the reasons given, to say which electron was moved to which substate by the excitation. On the other hand, it seems necessary to assert that the electrons that changed state were not those belonging to other atoms in the gas. The physical justification for this lies in the way that the energy levels of such gases follow the Maxwell-Boltzmann distribution law which would, as in Figure 1, lead to the conclusion that the electronic systems forming part of the separate atoms are distinguishable individuals. The space between these potential wells is occupied by electrons "at infinity" which remain totally unaffected by the events in any well and which therefore do not form a coupling or link between the systems. Here again there is a physical picture which bears a distinct resemblance to that of consciousness. Corresponding to the consciousness of an individual spanning its contents, we have the electronic wave spanning the crystal lattice, and corresponding to the privacy of each mind, we have the independent Maxwellian behaviour of separate quantum systems or crystals. The electrons forming the background for the quantum systems are neither interacting with themselves nor with the electrons within each system. It is only when trapped in a well that, through the exclusion principle, they are forced to do so and when that happens, since electrons are indistinguishable, any interaction forms one elemental event.

4. QUANTUM SYSTEMS AND NEUROPHYSIOLOGY

It is now appropriate to discuss the physiological embodiment of the foregoing. A study of neural transmission seems at first sight to exclude the existence of quantum systems spanning large regions of the brain. In the first place, propagation of energy along nerves appears to be by action potentials which involve only local currents and hence only local quantal events. The spatial separation of neighbouring spikes by regions of nerve in the refractory phase is such that they form independent systems. As Brink (1951) stated, the all-or-none law of neuronal response, in which communication is by transient changes of structure or pulses of fixed magnitude but varying rate, presents the psychologist with a fundamental problem. Something more seems required for the explanation of mental connectedness and continuity.

An equally serious difficulty in the way of constructing extensive unitary brain systems is found in the synapses through which neurons communicate,

for these characteristically contain a cleft 200nm wide across which the spike is transmitted not electrically but by the release of chemical transmitter substances, the various molecules of which are quite separate quantum systems.

The first of these two problems would be lessened if the spike potential were not the neural message itself but, as it were, its power supply which induces electrical activity in some suitable intracellular structure in which electrons are distributed somewhat as in a crystal. The notion of conduction or semiconduction in biological macromolecules has been familiar to biologists since Szent-Gyorgyi (1941) claimed that protein structures could have conduction bands along which electrons could migrate; but although doubt has been cast on this (Blumenthal, 1981), there is no doubt of long range energy transfer in complexes of protein molecules. Unfortunately, according to Blumenthal, the mechanism for such transfer seems often to be by resonance transfer, in which resonance is passed nonradiatively between neighbouring molecular sites. However rapidly it might happen, any long distance transfer would thus seem to consist of a sequence of separate events, not one elemental or quantal event as the unity of conscious events seems to demand. A more suitable speculation, therefore, might be that some intraneural structure has the property of superconduction which allows long range correlation between electrons. Little (1965) has given a theoretical account of how long protein molecules with sidechains in which electrons resonate from one site to another can give rise to bound pairs of electrons distributed throughout the material which, through their great number and overlapping distributions, are required to obey the exclusion principle and to form a quantum system. Cope (1973) has suggested that cytochrome-oxidase at the water-lipid junctions of cell membranes may be superconducting and DNA has a structure similar to that found necessary for superconductivity by Little. There may conceivably be related structures that behave in the appropriate way. Such substances could form organised lattice structures spanning whole neurons and if the electronic system within a neuron were to be excited by field effects generated by the spike potential this would constitute one elemental, indivisible act.

However, the act would be confined to the neuron in question unless some process could be found enabling electrons on opposite sides of a synaptic cleft to become coupled. Some, though a minority, of vertebrate synapses possess greatly narrowed clefts, accompanied by intercellular channels known as gap junctions (Sotelo, Llinás and Baker, 1974), and which are associated with electrical transmission. Unwin and Zampighi (1980) have analysed how these junctions open to join the intracellular spaces. The usual account (Kuffler and Nichols, 1976) of the functioning of these narrow clefts is that by preventing its shunting into the extracellular fluid, they allow the local current circuit to pass unhindered from cell to cell. That may be true at the level of the spike potential but gives the gaps no electrical function. At the level of the supposed

superconducting core it may be that the opening of the gaps, having been powered by the spike potential, the lattice structures of the two cells are brought into contact so that the events within them are happening to a single quantum system. If the gaps only open when both cells are firing, the second cell will only be coupled with the first when both are active. By such means, large oscillatory systems whose contributory neurons will depend upon sensory input could be formed. (Of course other mechanisms for coupling the electronic systems of co-active neurons might be postulated. For example, Ruffner *et al.* (1980) show how electric fields may span even high-resistance synapses. But it is to be observed that the cleft width in electrically transmitting synapses is about 2nm (Kuffler and Nichols, *op. cit.* p. 158), somewhere around the electronic tunnelling distance (deVault and Chance, 1966) and similar in extent to the insulating junctions (about 1nm) between superconducting bars across which direct current can be observed to flow in the Josephson effect and which is attributed to phase coupling of the electron pairs in the two bars through quantum tunnelling.) The changing contents of consciousness, on this supposition, reflect the fact that continually different cell systems are being switched into and out of the overall quantum system. The vast number of such systems, corresponding to features not currently present, which are uncoupled from the main quantum system remain quantum systems in themselves but play no part in consciousness. They, as much as "matter", correspond to J.S. Mill's "permanent possibility of sensation".

5. MENTAL EVENTS, THE PRESENT AND TIME

If it is true, as many following Titchener (1909) have claimed, that consciousness is entirely made up of sensations and that these correspond to the activation of appropriate feature detecting cell systems and their coupling to the main brain quantum system (i.e. to activity in areas serving other sense modalities) via brainstem structures, we conclude that a mental event corresponds to a quantal uptake or loss of energy by the whole presently coupled sensory system. This state of affairs has profound implications for what appears in consciousness.

Each new sensory change, however small, changes the mental event representing the contents of consciousness; tends, that is, to prepare the sensory brain in a state corresponding to the total sensory array at that time. However, as Haldane (1963) pointed out in an article that anticipated the present view of the quantal nature of mental events, the energies of neighbouring states in a system as extensive as the sensory brain are very close together. This means that the transition from one mental state to another involves very precisely defined, because very small, amounts of energy. Now, the time-energy uncertainty principle dictates that the more precisely the energy of a quantal transition is

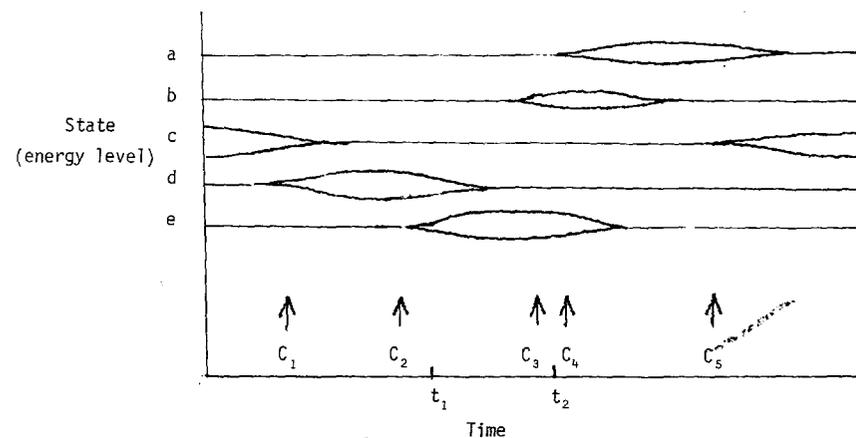


FIGURE 4 Diagram to illustrate how the successive presentation of five stimulus configurations (C_1 to C_5) which, other things being equal, would prepare the brain in a corresponding state (d, e, b, a and c respectively), affects the probability that the system is in each state. This probability is represented by the width of the bulge in the line representing each state.

determined the less precisely it may be timed. For stimulated transitions, say, from state A to state B which involve precise energies, the probability that the system is in state B rather than state A changes continuously over time, even though measurement on the system at any time would show it to be either in state A or in state B. Thus, although a measurement of a state will always give an unambiguous result, the state itself must be viewed as a changing mixture of states. Haldane calculated that such transitions in a system as extensive as the brain might be expected to take about a second. However, sensory inputs arrive at a much higher rate than one a second and so at any time the total system is in a changing mixture of states in the above sense. Haldane used this fact to account for how events in consciousness seem to overlap and include each other so that the psychological, specious, present is not of infinitesimal duration but seems to include events spread over about a second. Schematically the situation is as in Figure 4 which shows the effect of five successive sensory configurations (C_1 to C_5) upon the state of the sensory quantum system.

Given a relation between rate of stimulus presentation and transition time like that in the diagram, we should conclude that the conscious system will never certainly be in a state. Rather it will be in several states which are spread in time: a measurement on the system at time t_1 would show it either to be in state d or e, while at time t_2 such a measurement would show it either to be in state a or b. The critical moment which we are equating with the

state of the system therefore has a length governed by the time it takes for any constituent state to enter and be purged from the mixture of states. As Haldane (1963) suggested, in their possession of consciousness human beings have the opportunity to examine the quantum theoretic assertion that quantal events have no detail (in that there are no states between the possible energy states, so that transitions are all or none). It might be added to this that, similarly, human observers might examine the physical assertion that although observables are discrete, the state variables change continuously. Bohm (1980) referred to the Zeno-like paradox that a moving object seems to be apprehended as a series of "stills" each separate and self-contained, yet the observer senses an individed flow of movement. He proceeded to say that this 2000 year old problem still lacked a satisfactory answer, but it is proposed here that quantum theory gives a perfectly adequate answer, viz. the sensory system is in a continuously changing mixture of discrete (or orthogonal) states. The changing probability of being observed to be in a state is to be identified with the sense of flowing movement and the discrete (but coexistent) states with the "stills".

It is arguable that the construction of an abstract dimension of time depends crucially upon the fact that the irreducible instant in sensation is itself changing. If sensory events occurred at a much slower rate than transitions, as schematised in Figure 5, there would exist a series of discrete mental events well separated in time with nothing to indicate their inherent continuity and ordering.

The non-mental nature of the pure states between transitions is weakly supported by the fact that conscious events are always changing, so that transition

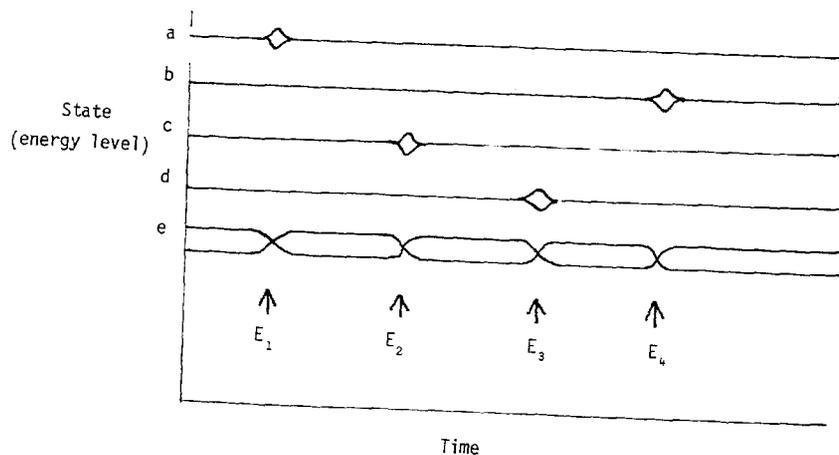


FIGURE 5 Diagram of changing states in a sensory system in which inputs occur at a slower rate than transitions. The corresponding mental events (the transitions E_1 to E_4) are seen to be non-overlapping and so contain no information as to their ordering.

seems the crucial mechanism, and is further suggested by the fact of general anaesthesia. Presumably the effect of an anaesthetic is, through nullifying membrane activity, to leave the system in *some* stable state (perhaps the ground state), but that unchanging state corresponds to unconsciousness. The mental existence of the observer of Figure 5, therefore, would consist of a series of momentary disconnected comings to life.

Mental events like any other physical events, then, only occur when matter waves change state and the continuity of a person's biography consists in the string of overlapping transitions between states of the matter waves trapped within the potential well formed by the atomic nuclei of his sensory nervous system. Only in such transitions does the indivisible electron wave have to keep out of its own way, so to speak, in order to obey the Pauli Principle.

6. MEASUREMENT, THE PREPARATION OF STATES, AND REPORTING ON CONSCIOUSNESS

We have distinguished between the state of a system which is capable of smooth variation and observables (e.g. physical quantities like energy) which are discrete and experimentally always yield exactly one value and so, in any single experiment, misrepresent the underlying process. It might be asked, if this is so, how it is possible to report upon consciousness and its contents, for surely, in order to report upon events in a system, measurements must be made upon it so that one would expect the report not only to misrepresent the state of affairs in the above way but also to prepare the system in a new state which would be a function of the measurement and so not an uncontaminated state of the system itself.

To answer this question, it should be pointed out that the statement that a person observes his awareness, or part of it, is not as simple as it may appear. The mental activity of a person is more extensive than his consciousness and a great proportion of it never enters his consciousness. Freud (1954) distinguished between conscious and unconscious subsets of mental activity and James (1890) spoke of the "flights and perchings" of thought. The perchings refer to those moments during thinking when images, or phrases representing suggested solutions to the problem, presented themselves to the thinker's consciousness, whereas the flights were those inferred processes intervening between the perchings and which produced them by some means entirely outside the thinker's awareness. According to the above hypothesis, there is no necessity for these processes to be unconscious in themselves. All that is required is that the association cortex (A) shall be permanently decoupled electronically from the sensory system (S), even though they may interact intimately by some non-electronic process. The functions of these two systems are entirely different:

S serves as the definer of moments, the coordinator of disparate inputs into elaborate *patterns* of input, while A serves to anticipate subsequent patterns on the basis of the present one. This it seems to do by forming what Bindra (1976) calls contingency organizations between sets of features (gnostic assemblies) that experience shows to stand in a predictive relation with other such sets. The production of motor responses is supposed to be brought about when such a contingency organization predicts a situation capable of eliciting the movements in question (or preactivates sensory features connected maturationally to the appropriate motor apparatus). Now A only requires as input the *outputs* (corresponding to various sensory features) of S to use them predictively and, ultimately, to base a vocalised description upon. It follows that any "description" of consciousness or its contents must amount to a listing of features present — the features themselves cannot be described. However, if an observer sets himself, for example, the task of describing the "straightness" of a line, this instruction, through a multitude of contingency organizations of which he is not aware, will preactivate the neurons of the straightness (or edge-detecting) systems, which will have the effect of enhancing activity in those regions at the expense of others. The conscious experience will then be more purely one of "straightness". Thus the reporting on a certain demanded aspect of experience enhances that very aspect. However, the report cannot do anything but state whether the aspect, or associated aspects, is present. Therefore, while the A system has been set an impossible task, it yet indicates to the S system the solution it cannot verbalise. According to this view, when consciousness is apparently being reported upon, in these examples, there is a one-to-many mapping of the association cortex's report onto the activity within the feature analysers that allow the report to be made. Schematically the situation is as in Figure 6.

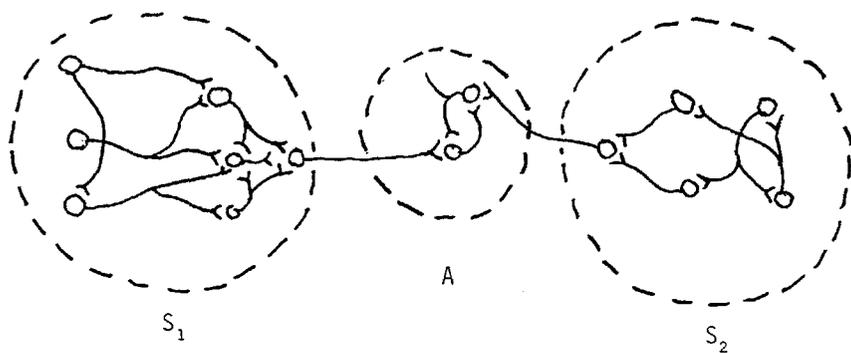


FIGURE 6 Diagram showing the nature of association between sensory features. A_1 and S_2 are feature analysing circuits whose outputs may be associated by the circuitry in A.

If it be supposed that all motor responding is produced by the A system (through its selective priming of sensory apparatus adequate for the response) it is clear that no description can be given of internal aspects of feature experience, since no information about it is communicated to the A system.

7. DIFFERING SENSORY QUALITIES AND NEURAL ORGANIZATION

The last question concerning conscious awareness that will be considered here, is that which Schrödinger called the mystery of the sensory qualities. He stated the difficulty in terms of there being nowhere in the neural account of brain activity any colour or emotion. But the reason for this is plain: the neural account of brain activity is not that activity but rather a conceptual description based on a series of observations of the activity's external effects. Here again the state of a system should be distinguished from its corresponding observables. On this basis, it may be asserted that redness, for example, *is* in the brain if by that we mean that redness constitutes the activity in some part of what outwardly looks like a brain. Sensations are the process in itself and not observations carried out on that process.

The problem of differing sensory qualities is why activity in some parts of brain is accompanied by sensations of colour while in others it is accompanied by sounds and so on. It is possible that a consideration of the nature of these various modalities could lead to some notion of what the circuitry involved in it would look like if observed. This task is somewhat similar to that of the astronomer who tries to deduce the four dimensional shape of the universe from within his three dimensions. The observer's task is to discover his shape without ever going outside his boundaries. The main difference between the two is that the observer extends throughout the pattern of activity whose shape he is to deduce.

Now each sense modality in reality consists of a number of submodalities somewhat arbitrarily conjoined. For example, the visual modality, representing all those sensations achievable by opening the eyes, contains colour, shape, movement and depth aspects among others. It is not clear that straightness and redness as submodalities are more akin (more essentially "visual") than, say redness and the sound of a pure middle C and so the investigator should be prepared to analyse each modality into its phenomenally irreducible aspects. If he succeeds, he will probably have got down to the level of feature analysers like those of Figure 6, and the reason for their irreducibility will be that such analysers have only a single output. At any rate, he will not be able to dissect his experience further.

We may predict, therefore, that little progress will be made in discovering why the activity in the "yellow" circuit gives a feeling of yellowness, but this

will not prevent some progress from being made. For example, "depth" or spatial location may be felt in at least two modalities, the visual and the auditory. For each of these sensory systems compares inputs from two sides to achieve its end. It will not, therefore, be surprising if some aspects of their circuitry are rather similar. If they are, it would seem appropriate to say that depth is a separate modality but with independent realisations in the visual and auditory spheres.

This hint that the quality of a sensation depends on the organisation of the corresponding feature detectors prompts the question as to what principles of organization are the crucial ones. If modalities are studied as wholes an answer to this question is suggested. In vision, for example, different aspects of a scene are contributed by different levels of the nervous system. Thus, the spatial location of an object requires the operation of the superior colliculus, while its detailed features are analysed by the cortex (Schneider, 1969). This situation in which different types of feature are analysed in different locations separated by rather lengthy fibre tracts is perhaps to be expected, since more recently evolved brain structures should provide more detailed information about the environment than older ones. Despite this spatial separation of the analysers involved, the location, brightness, colour and shape of an object are felt to be intimately connected and intertwined — the colour of an object is felt to be coextensive with the object and never (as in colour printing) do the colour and the shape fail to coincide. This observation makes it clear that it is not the geometry of the neural organization that is crucial, for that would seem to overemphasize the spatial differentiation of the various analysing systems. Rather the sensation corresponds to the topological description of the system, since that is concerned with relations of containment, adjacency and so on which are independent of geometrical transformations; so that, for example, one object may contain another even though the bulk of the two objects may be spatially widely separated. By such means we may hope to explain how an object always "contains" its colours even though shape and colour are analysed by different structures.

Since most of perception is of qualities at locations, it is pertinent to ask why some patterns of neural activity are spatially differentiated and some non-spatially differentiated in sensation. In Figure 7, two schematic patterns of neural activity are represented.

From the previous discussion, it appears that the activity within neural fibre tracts does not contribute to awareness but merely connects different sets of feature analysers reflecting the fact that topologically a line is a point. We will provisionally assume therefore that neural activity contributes to conscious awareness when it is organized. The minimum unit of organization is a loop and it is in terms of these that Figure 7 will be discussed.

In (a) each loop of three adjacent points is either in contact with another

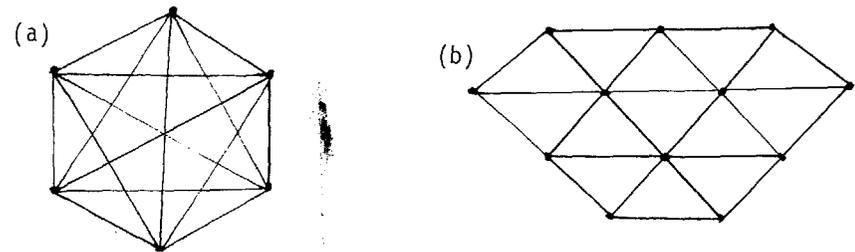


FIGURE 7 Two imaginary patterns of neural activity to illustrate the argument in the text. When an intersection does not have a dot, the lines are not joined but merely cross.

such loop or with many that are. There is a high degree of adjacency between loops. In (b), on the other hand, each loop of three points is adjacent only to a select few other loops. Now, it is characteristic of "space" that each point is adjacent to very few other points in exactly the same way as the loops of (b) are adjacent. Although the neural network of (a) or (b) may, seen from the outside, be warped, stretched or crumpled out of recognition, the experimenter of the activity within it will only be aware of the adjacencies, so that to him the elements of (a) will seem to possess a point quality of some kind, since only for a point are all the "parts" adjacent to each other. The exact nature of the quality will depend upon the number of points and their pattern of interaction — the graph theoretic concept of "genus" (the number of "handles" that must be "sewn" onto a "sphere" in order to embed a figure) is probably relevant here: the topological inequivalence of graphs of different genus may well be one basis for the seemingly irreconcilable differences between sensory qualities. It must remain an empirical matter to establish which graphs correspond to which sensations, in exactly the same way as it was an empirical matter to discover which molecular structure corresponds to what we know as water.

Now, if a network of type (a) be attached to each node of network (b) by a tenuous link, say a single fibre, from the point of view of the experimenter of the network, it can be seen that non-spatial, punctate, qualities will be felt at each node and since the various cycles of (b) are held apart in a spatial manner, for the experimenter the quality in question will be felt, as in seeing a coloured object, to extend over an area of space. In some cases the mutual adjacency of the parts of a feature analyser may be less extreme than in the above example. This will add a certain spatial aspect to the sensory quality. Rich (1916) identified a dimension of voluminousness of sounds and parametric studies by Thomas (1949) showed that pure tones of e.g. 200Hz, 22db and 4000Hz, 100db were consistently judged as of equal volume.

Sensory qualities are "mysterious" because there is no output to the A system from their internal parts. If evolution had found it expedient to provide such outputs from, say, the various subprocesses involved in the redness circuit, then human observers would be able to describe it in greater detail. However, not only would this "description" be of the strictly limited kind referred to above but also the subprocesses themselves would then become "mysterious". Descriptions of sensation therefore can shed light on the topological arrangement of feature detectors, but only in a general way enable the internal structure of feature detectors to be established.

Anatomically the brain has just the topological organization described above. All sensory inputs pass through the reticular formation, which is very highly internally connected, on to higher and higher levels of midbrain and cortex: in the visual regions each of these higher structures arises out of its own peculiar lower structure and has very little lateral connexion with similar neighbouring structures. In this way, the topological containments (of quality-mechanisms in location-mechanisms) that seem necessary for the construction of visual space are achieved. Different modalities have their separate bundles of columnar machinery with varying internal arrangements. Thus the geography of the brain reflects the characteristics of conscious experience with its different modalities (the different sensory areas) unified into a single "self" (joined into a functional unity via the reticular formation and other midbrain structures). Commenting on the dotted grid-pattern of activity in cortical edge-detectors when one eye of a monkey is exposed to a set of vertical stripes, Hubel and Wiesel (1979) write, "Imagine the surprise and bewilderment of a little green man looking at such a version of the outside world!" However, the cortical activity is not a version of the outside world but merely part of one: for the total version, all the appropriate activity from lower centres would have to be included. The actual "little green man" is embedded in the activity at all levels simultaneously and because he is only aware of topological relationships in that activity he sees a set of vertical stripes. Whereabouts in the cortex the verticality of each part of each stripe is registered is irrelevant to the resulting perception and, were he well-informed, the *geometric* external appearance of his brain activity need not surprise him at all.

8. CONCLUSION

The sensory brain can thus be viewed as a collection of dense networks of varying internal connectivity joined together by a kind of tree structure of neural tracts. These networks are individually capable of being activated and switched into (and out of) the total network. It is quantal electronic transitions within the currently connected networks that form the overlapping conscious

events and thus the consciousness of the individual. Other regions of brain do not contribute to consciousness for one, or more, of three reasons: their electronic disconnexion, their inactivity and their sequential, as opposed to spatial, mode of action. Concerning disconnexion, it seems plausible that electronic coupling only exists between "hardwired" circuits of cells such as those of feature detectors and not between cells whose ability to excite each other is conditional upon experience and which must be reversible. If so, the "flights" of thought take place in the latter kind of cell. It is possible that there is some kind of consciousness in other tightly knit regions, such as the cerebellum which, as an autonomous controller of movements, is independent of the main sensory system. The consciousness that is referred to as belonging to the individual corresponds to the quantal events in that region of the brain, whose activity is a necessary precursor of so called voluntary movements and of speech. Any other consciousness within the individual's brain is as foreign to that individual as another person's consciousness and for the same reasons. With regard to inactivity, each potential, but presently unrealised sensation, corresponds to cell systems which, through lack of input, are inactive so that they are both decoupled from the main system and are making no transitions. (They are effectively anaesthetised.) Even if electronic events were taking place in them as a result of, say, spontaneous activity, such events would be both rudimentary and switched out of the main system, so that at any particular time no contribution is made to awareness by large tracts of sensory brain. Finally, concerning a sequential mode of working such as we might expect to find in the association cortex, whose function is to predict one sensory array from a previous one, we may note that to get from one array to another neural events must pass through some process which is not an array and since all sensation forms an array, this process will not contribute to consciousness.

There is no mystery of how the arrangement of different sensory mechanisms produces the corresponding sensation, for these mechanisms must be seen merely as conceptual abstractions and not things-in-themselves. It is the privilege of human observers to be things-in-themselves that have (via the sensorimotor system) some limited capacity to discuss their own nature with each other. Other things-in-themselves (atoms, molecules and larger structures) must remain forever mute; but it is to be presumed that, in principle, they differ from us only in the degree of complexity of their existence.

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Evolution and Atoms

C.N. VILLARS

It is argued that the modern evolutionary conception of nature forces us to conclude that even simple atoms and molecules are psychophysical systems. It is suggested that modern physics has already, tacitly, begun to describe the psychic aspect of microphysical objects. Quantum nonlocality is interpreted as a form of acausal perception and seen as the foundation of both the paranormal and the more complex overlying phenomena of everyday psychology.

We know ourselves both as centres of subjective experience and as objective bodies. Not only are we made of flesh and blood but also of sensations, thoughts and feelings. If we accept the modern theory of evolution, this fact — the co-existence of these two complementary aspects of a human being — has important implications for our conception of the simplest material objects, i.e. atoms and their constituents.

Human beings have evolved from the higher mammals. These also experience sensations and feelings. We know this from the fact that their sense organs strongly resemble our own, and that they exhibit the gestures and reactions which characteristically accompany our own various emotions. Who, in the presence of a shrieking, injured animal, or seeing an animal cower away from him, can seriously doubt that it is experiencing feelings of pain or fear similar to our own? The more developed higher mammals, such as apes or dolphins, also exhibit some degree of reflective intelligence.

The further back down the evolutionary tree we go, the harder it becomes to imagine the kind of subjective experience the creatures possess. Their sensory apparatus and forms of behaviour are quite unlike ours. Indeed, at a low level, such as that of the insects, for example, we may be inclined to believe that they have no inward experience at all, but are mere mechanical automata. In that case, where should we draw the line? Which were the first organisms to emerge capable not only of acting and reacting but also of experiencing the world around them?

This question assumes that it is possible for a transition from inert material objects to living centres of experience to have occurred in the process of evolution.