T-166a

THE IMPLICATE BRAIN

Initiation:

It was at Christmas-time 1975 that the issues of quantum physics became relevant to my explorations of how the brain works. I had come to an impasse with regard to two aspects of brain function: One impasse was the dilemma of whether to think about the events which occurred at the junction between, and in the fine branches of, nerve cells as wave forms or as statistical aggregates. This dilemma appeared to me to be similar to that faced in quantum physics where electrons and photons, particles, at times displayed the characteristics of waves.

The second impasse had to do with perception. Evidence was accumulating to show that the nerve cells of the part of the cerebral cortex connected to the retina responded to a transform of the retinal image, a transform which yielded what Fergus Campbell and John Robson of Cambridge University (1968) called "spatial frequency." Since the same transformation also occurred in the formation of the retinal image by the pupil and lens of the eye, the question arose as to whether the "spatial frequency" domain also characterized the physics of the visual world which we perceive.

I took these issues to my oldest son, a physicist and superb teacher, who gave me an intensive course in quantum physics over the Christmas holidays. Toward the end of his really excellent briefs, and having completed some of the essential readings such as "Physics for Poets" (March, 1978) and the like, I remarked how happy I was to be a neuroscientist and not a physicist: we have our problems but, by comparison to what seems to be the conceptual muddle of quantum physics, we're doing alright.

My son replied, as have many other physicists (and also Karl Popper the philosopher when I faced him with the same issue) that modern physics is not interested in concepts; the mathematical formulations are so precise and have had so much predictive value that conceptualization is not only not necessary but gets in the way.

"However," he added, "there are a few physicists who don't agree to this. They are far out types who would appeal to you." And he gave me some names such as Max Jammer and David Bohm, and references to the books they had written.

Synchronicity:

Back at Stanford, not a week had elapsed before I was asked whether I had heard of David Bohm. My reply was professional. Had I not just "graduated?" Of course I had heard of David Bohm. Despite my hubris, I was gently advised of two papers which Bohm had written and which had been published in Foundations of Theoretical Physics in 1971 and 1973.

This was on Friday afternoon. Saturday morning I awoke early and read the two papers. Bohm, in simple clear language, declared that indeed there were conceptual problems in both macro- and microphysics, and that they were not to be swept under the carpet. The problems were exactly those which my son had pointed out to me. And, further, Bohm suggested that the root of those problems was the fact that conceptualizations in physics had for centuries been based on the use of lenses which objectify (indeed the lenses of telesopes and microscopes are called objectives). Lenses make objects, particles.

Should one look through gratings rather than lenses, one might see a holographic-like order which Bohm called implicate, enfolded (im-plicare, Latin to fold in). He pointed out that in a hologram the whole is enfolded into every portion and therefore the whole can be reconstructed from each and any part.

I was exuberant. Bohm held the answers which I had been seeking. I had for years (Pribram, 1966; 1971) maintained that part of the puzzle of brain functioning, especially the distributed aspects of memory storage and the transformation into the spatial frequency domain, resembled the process by which holograms are constructed. My hunch that perhaps the physical input to the senses shared this transform domain seemed to be sufficiently realistic to be shared by one of the major contributors to theoretical physics.

That Saturday morning I was performing some surgery and my secretary had asked to be present since she had never seen me perform a brain operation. During the surgery (which went without difficulty) I explained not only what I was doing to the assembled team, but also told them of the good news contained in David Bohm's two theoretical articles. My secretary asked "Is this the same David Bohm who has invited you to a conference at Brockwood Park to meet with Krishnamurti?"

I had not registered that invitation in my memory, but we looked it up later that morning and indeed there was my third encounter with David Bohm that week! Obviously we were meant to meet.

Meet we did, and often over the next decade. I went to London even before the Brockwood Park conference and have returned there many times to thrash out specific problems with David Bohm and his close associate, Basil Hiley. Always, both were gracious and patient in the face of my ignorance, and explained everything to me in great detail.

Only once did Bohm become impatient: I challenged him when he expressed the belief that the universe was all "thought" and reality existed only in what we thought. I expressed dismay with this perspective. Why, if that were so would I need to perform experiments and why would they so often come up with results contrary to what I had been thinking. Bohm answered that that was because my thoughts were probably muddled --- to which I unfortunately had to agree. But then I noted that the experimental results were usually very clear and not muddled at all, and therefore reality seemed not to reflect my muddled thoughts.

The argument became somewhat heated and I decided that, since Bohm had not been feeling too well, I had better back down. (Bohm went into the hospital to have heart bypass surgery a few weeks later. Since I did not win the argument, I seem not to bear responsibility for this turn of events. After all, my thoughts could not have determined David's difficulties with his heart since I was not aware of them. Bohm has recovered fully, and neither he nor Hiley have blamed me for the episode.)

The Plenum:

Are the events occurring at the junctions between and in the fine dendritic branches of nerve cells to be considered as waves or as statistical aggregates? What makes electromagnetic energy manifest as particles under some circumstances and as waves under others? Is Niels Bohr's complimentarity formulation (1934) the best we can do?

An answer to these questions took the following form and was reached in several steps. Bohm indicated to me that it was inappropriate to ask these questions in the form that I did. The question could not be framed in terms of either/or; rather, waves and particles (statistical events) mutually imply each other. In this formulation, Bohr's complimentarity was replaced by implication, an entirely different conception. Bohr had invented complimetarity to indicate that at any one moment, with any specific technique, only one aspect of a totality could be grasped. Heisenberg (1955), addressing the same issue, proposed the uncertainty principle: we can never be completely objective in our knowledge because knowing involves the techniques by which we make our observations. As Wigner, Heisenberg's pupil, has pointed out (1969), modern physics no longer deals with observables but with observations.

Bohm's alternate conceptualization of the wave/particle implication demonstrated that indeed both aspects of the totality could be grasped in one setting. I noted that physics had made conceptual sense in the days of Clerk Maxwell when the universe was filled with an ether and particular events made waves in that medium. The modern era of conceptual confusion seemed to arise with the abandonment of the ether by Einstein in his special theory of relativity, and by Michaelson and Morley (See Holton, 1973) on the basis of their failure to demonstrate a distorting drag on the presumed ether produced by the earth's rotation.

So why not reinvent the ether? Perhaps give it a new name so as not to confuse the concept with the one now discredited. Dirac (1951) and others had already made the same proposal. In fact, Bohm had suggested this solution to Einstein in 1953 and Einstein had replied that such a solution was a cheap shot, meaning that it simply replaced one set of problems with another. Nonetheless, Bohm and Hiley pursued the idea, and proposed (1975) the existence of a medium which they called the "quantum potential." Events, particles, perturbed the medium in such a way as to account for the wave aspects of quantum mechanics.

Hiley and Bohm then demonstrated in a computer simulation how to simultaneously account for both the particle and the wave aspects of the single and double slit experiments (1976). These experiments had epitomized the conceptual dilemma of quantum physics as expressed in the infamous Schroedinger's cat (which seemed to be both alive/dead) and the collapse of the wave function (which indicated that when the cat was actually observed, the observer decided that the cat was indeed dead or alive).

The mutual implication of particle and wave was thus demonstrated. True, the quantum potential as a medium had to have some special properties. It certainly could not produce drag. It had to be a potential which was manifest to observation only when perturbed (by a particular event). But is this any worse than ignoring infinities in equations when it is necessary to do so in order to make predictions?

The concept of a quantum potential does indeed rationalize not only quantum physics but also cosmology. When a plenum composed of electromagnetic energy and plasma rather than an empty vacuum characterizes the universe, there is no longer any need for someone with a pea shooter on Andromeda to shoot particles (photons) toward the earth so that we might see them. Rather, a perturbation of the quantum potential occurs on Andromeda, the perturbation is transmitted as a wave form to us, where it reaches the shores of our visual receptors. Here the wave breaks into particles and the breakers are perceived as light.

Non-local Processes in the Brain:

Non-locality was one of the basic issues which had stimulated my initial foray into physics. When patients suffer damage to their forebrains they do not lose particular memory traces. They may not be able to speak or to identify objects visually or tactily. They may even lose the ability to recall a whole mnemic category (Warrington, 1983), but individual specific memories seem to be sufficiently distributed so that they may be recalled despite extensive damage. The memory traces may, of course, be located elsewhere in the brain than in the damaged part, but then the mechanism by which the traces are recalled must to some extent be distributed or else there would be at least an occasional instance where some single isolated memory loss would be produced.

The invention of holography seemed to hold the key to understanding this distributed, non-local aspect of memory storage and retrieval, as well as the constructive aspects of perception. If, indeed, the input to the pupil of the eye came in the form of wavefronts of electromagnetic potentials, such potential orders had the distributed, non-local, enfolded characteristics which were also captured in the process of holography. As well, certain aspects of brain physiology, such as the fact that single cells in auditory somatosensory and visual cortices resonate to limited bandwidths of the energy spectrum, appeared to share the attributes of the holographic process (Pribram, Nuwer & Baron, 1974). These tuning curves reflect the dendritic non-propagated slow potentials --- the hyper- and depolarizations --- which characterize the dendritic patterns in receptor surface and cortex which are constituted in response to the sensory input.

On the basis of Bohm's conception, it is not the right question to ask whether these slow potentials (hyperpolarizations and depolarizations) occurring in the receptors and in the nerve cell structures of the brain are to be conceived as statistical events or as waves. Polarizations occur in a medium provided by such cells as the Mueller in the retina and the oligodendroglia cells in the brain, cells which envelope the fine branches of neurons. This medium can be conceived as a manifold within which the polarizing events are produced.

Mutual implication, rather than either/or, best describes the microneural relationship. Thus, the mathematical formulations which have been developed for quantum field theory should go a long way toward explaining such phenomena as the saltitory effects which occur in dendritic networks and are responsible for influencing nerve cell output in an apparently non-local fashion.

Spacetime and the Implicate Order:

An equally important step in understanding came at a meeting at the University of California in Berkley, in which Henry Stapp and Geoffrey Chew of the Department of Physics pointed out that most of quantum physics, including their bootstrap formulations based on Heisenberg's scatter matrices (Stapp, 1971; Chew, 1971), were described in a domain which is the Fourier transform of the spacetime domain.

This was of great interest to me because Russell and Karen DeValois of the same university had shown that the spatial frequency encoding displayed by cells of the visual cortex was best described as a Fourier transform of the input pattern (1980). The Fourier theorem states that any pattern, no matter how complex, can be analyzed into regular waveform components of different frequencies, amplitudes, and (phase) relations among frequencies. Further, given such components, the original pattern can be reconstructed. This theorem was the basis for Gabor's invention of holography (1946).

At a subsequent meeting Bohm agreed that in his concept of an implicate order (at least at a first level) the enfolding was of space and time, and that at this level the implicate and the explicate (spacetime) domains were related by a Fourier transform.

Sensory experience is in spacetime. When we say that we wish to make sense of something we mean to put it into spacetime terms, the terms of Euclidean geometry, clock time, etc. The Fourier transform domain is potential to this sensory domain. The waveforms which compose the order present in the electromagnetic sea which fills the universe make up an interpenetrating organization similar to that which characterizes the waveforms "broadly cast" by our radio and television stations. Capturing a momentary cut across these airwaves would constitute their hologram. The broadcasts are distributed and at any location they are enfolded among one another.

In order to make sense of this cacophany of sights and sounds, one must tune in on one and tune out the others. Radios and television sets provide such tuners. Sense organs provide the mechanisms by which organisms tune into the cacophany which constitutes the quantum potential organization of the elecromagnetic energy which fills the universe.

Coda:

This is my understanding, thanks to my son John; to Henry Stapp and Geoffry Chew; and to Basil Hiley and to Eloise Carlton, who often served as creative interpreter for our deliberations. But above all, I am indebted to you, David Bohm, for providing the inspiration to pursue these ruminations and to give substance to them.

REFERENCES

CAMPBELL, F. W. & ROBSON, J. G. (1968) Application of Fourier analysis to the visibility of gratings. J. Physiol., 197: 551--556.

MARCH, R. B. (1978) Physics for poets. New York: McGraw Hill.

BOHM, D. (1971) Quantum theory as an indication of a new order in physics. Part A. The development of new orders as shown through the history of physics. Foundations of Physics, 1: 359--381.

BOHM, D. (1973) Quantum theory as an indication of a new order in physics. Part B. Implicate and explicate order in physical law. Foundations of Physics, 3: 139--168.

BOHM, D. J. & HILEY, B. J. (1975) On the intuitive understanding of non-locality as implied by quantum theory. Foundations of Physics, 5: 93--109.

BOHM, D. J. & HILEY, B. J. (1976) Some remarks on Sarfatti's proposed connection between quantum phenomena and the volitional activity of the observer-participator. Psychoenergetic Systems, 1: 173--179.

BOHR, N. (1934) Atomic theory and the description of the universe. Cambridge, England: Cambridge Univ. Press.

CHEW, G. F. (1971) The bootstrap idea and the foundations of quantum theory. In T. Bosom (Ed.), Proc. Coll. on Quantum Theory & Beyond. Cambridge, England: Cambridge Univ. Press.

DeValois, R. L. & DeValois, K. K. (1980) Spatial vision. Ann. Rev. Psychol., 31: 309--341.

DIRAC, P. A. M. (1951) Is there an aether? Nature, 168: 906.

GABOR, D. Theory of communication. J. Inst. Elec. Engrs., 93: 429.

HEISENBERG, W. (1955) Neils Bohr and the development of physics. New York: McGraw Hill.

HOLTON, G. (1973) Thematic origins of scientific thought. Cambridge, Mass.: Harvard Univ. Press (Chap. 9, pp. 261--352).

PRIBRAM, K. H. (1966) Some dimensions of remembering: Steps toward a neuropsychological model of memory. In J.Gaito (Ed.), Macromolecules and behavior. New York: Academic Press, 165--187.

PRIBRAM, K. H. (1971) Languages of the brain: Experimental paradoxes and principles in neuropsychology. Englewood Cliffs, N. J.: Prentice-Hall; 2nd ed. (1977), Monterey, Ca.: Brooks/Cole; 3rd ed. (1982), New York: Brandon House.

PRIBRAM, K. H., NUWER, M. & BARON, R. (1974) The holographic hypothesis of memory structure in brain function and perception. In R. C. Atkinson, D. H. Krantz, R. C. Luce & P. Suppes (Eds.), Contemporary developments in mathematical psychology. San Francisco: W. H. Freeman.

STAPP, H. P. (1971) S-matrix interpretation of quantum theory. Physics Review, D3: 1303-- .

WARRINGTON, E. & R. McCARTHY (1983) Category specific access dysphasia. Brain, 106: 859--878.

WIGNER, E. P. (1969) Epistemology of quantum mechanics: Its appraisals and demands. In M. Grene (Ed.), The anatomy of knowledge. London: Routledge & Kegan Paul.