A recent PNAS paper discusses a central issue for quantum consciousness theories: the existence of vibrational (phonon) coherence in biological systems (see Abstract and excerpts below). The authors argue that the phenomenon occurs in the weak but not in the strong version. A reply by Stuart Hameroff follows.

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Weak, strong, and coherent regimes of Fröhlich condensation and their applications to terahertz medicine and quantum consciousness

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Abstract

In 1968, Fröhlich showed that a driven set of oscillators can condense with nearly all of the supplied energy activating the vibrational mode of lowest frequency. This is a remarkable property usually compared with Bose–Einstein condensation, superconductivity, lasing, and other unique phenomena involving macroscopic quantum coherence. However, despite intense research, no unambiguous example has been documented. We determine the most likely experimental signatures of Fröhlich condensation and show that they are significant features remote from the extraordinary properties normally envisaged. Fröhlich condensates are classified into 3 types: weak condensates in which profound effects on chemical kinetics are possible, strong condensates in which an extremely large amount of energy is channeled into 1 vibrational mode, and coherent condensates in which this energy is placed in a single quantum state. Coherent condensates are shown to involve extremely large energies, to not be produced by the Wu–Austin dynamical Hamiltonian that provides the simplest depiction of Fröhlich condensates formed using mechanically supplied energy, and to be extremely fragile. They are inaccessible in a biological environment. Hence the Penrose–Hameroff orchestrated objective-reduction model and related theories for cognitive function that embody coherent Fröhlich condensation as an essential element are untenable. Weak condensates, however, may have profound effects on chemical and enzyme kinetics, and may be produced from biochemical energy or from radio frequency, microwave, or terahertz radiation. Pokorný's observed 8.085-MHz microtubulin resonance is identified as a possible candidate, with microwave reactors (green chemistry) and terahertz medicine appearing as other feasible sources.

Excerpts:

"In 1968, Frohlich showed how a driven collection of vibrational oscillators could achieve a highly ordered non-equilibrium state that has some properties reminiscent of Bose–Einstein condensation. Specifically, this Frohlich condensate has nearly all of its vibrational energy concentrated in just one of its collective motions, the motion of lowest frequency. Such a condensation would have a profound influence on the dynamical properties of the system, and there has been considerable interest in finding applications in physics, biology, and medicine.

Indeed, other phenomena that give rise to similar collective properties of a system such as lasing, superconductivity, and Bose–Einstein condensation are of great importance.

Frohlich condensation has even been postulated to play a central role in cognitive function within the Penrose–Hameroff orchestrated objective reduction (Orch OR) and related proposals. These controversial proposals evoke Frohlich condensation to maintain coherent quantum dynamics within microtubules inside cells on a physiologically relevant time scale (at least microseconds), enabling them to function as cellular quantum computing elements. In nerve cells, these elements are then presumed to interact with the electrochemical operation of the cells, leading to cognitive function. This is significant as Penrose has argued that linear (or, more generally, non-exponential) computational elements such as electrochemical-only neural networks are fundamentally incapable of cognition, undermining the basis for our current understanding of intelligence.

Despite intense interest, the 40 years subsequent to Frohlich's proposal have produced no unambiguous identification of a Frohlich condensate. The most substantial efforts have come from Pokorny who, interestingly, also considered microtubules. A range of other experimental detections of some of the key signatures of Frohlich condensates have also been reported or predicted. Pokorny's work concerns the interaction of MHz radio-frequency radiation with biological systems, and many other suggested occurrences of Frohlich condensates also involve either adverse or medicinal effects of microwave or terahertz radiation."

…

Discussion

"Although coherent Frohlich condensates are not biologically feasible, weak incoherent condensates within individual proteins may still be significant. Frohlich's original motivation was to explain the action of enzymes in terms of coherent excitation of vibrational modes. However, coherence is not essential as any energy redistribution could enhance enzymatic action."

…

Conclusion

"Historically, attempts to identify Frohlich condensation have focused on anticipated novel states of matter in which a large amount of energy is coherently channeled into a specific vibrational mode of a complex (biological) system. We show that no mechanical source of energy can produce such a condensate, and that although intense radiation could facilitate its formation, the energies required preclude its production in biological media. The most likely sources of coherent condensates are in microwave reactors and in systems exposed to intense terahertz radiation. Strong Frohlich condensates in which there is an extreme amount of energy incoherently activating the lowest frequency mode of the system are easier to produce and could be feasible to produce using mechanical energy sources, but still they remain unlikely in a biological environment. Coherent condensates could be detected from the intense coherent light emission that they must generate, whereas strong condensates could be identified through broadband emission at frequencies ranging from the system oscillator frequency down to at least 6 orders of magnitude lower. However, we find that experimental manifestations of Frohlich condensation are most likely to be observed via the effects of weak condensates. Weak condensates embody the enhanced non-equilibrium energy in all of the system modes associated with the energy flow from the input source to the surroundings. Further, enhancement of small but very significant

factors of the lowest-frequency mode can occur. Because chemical reaction rates vary exponentially with the energy in the lowest mode, these effects can produce dramatic changes compared with scenarios in which the input energy gets randomly distributed. Although one possible example of weak condensation has been detailed by Pokorny, many other possibilities associated arising from the interaction of radiation with biological system also exist. The possible role of Frohlich condensation in chemical kinetics remains largely unexplored, however.”
(OBS.: Thanks to Malcolm Dean for calling my attention to this paper)

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Alfredo Pereira Jr
19 March 2009 | 13:49

[Permalink]Below is Dr. Hameroff´s reply to the Reimers et al. paper.
Alfredo

Microtubules, Frohlich condensation and Orch OR
(Reply to attack on Orch OR in PNAS)
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In 1968 Frohlich proposed that certain biomolecules pumped by metabolic processes might exhibit coherent phonon dynamics, perhaps even macroscopic quantum coherence akin to Bose-Einstein condensation. The biomolecular requirements for coherent dynamics or condensation, according to Frohlich, were 1) an array or lattice of dipoles in a common voltage gradient, and 2) ample, non-coherent biochemical energy. Eligible candidates included membrane proteins, nucleic acids and cytoskeletal microtubules.

In the 1990s Penrose and Hameroff (1995; Hameroff and Penrose, 1996a; 1996b; Hameroff 1998; 2007) suggested that microtubules inside the brains neurons functioned as quantum computers supporting consciousness. The quantum computations were suggested to be synchronized by Frohlich coherence, terminated by Penrose objective reduction, and orchestrated by synaptic inputs and microtubule-associated proteins (MAPs). The Penrose-Hameroff model thus became known as orchestrated objective reduction: Orch OR.

In a recent paper in PNAS, Reimers et al (2009) describe three types of Frohlich condensation: weak, strong and coherent. Using the Wu-Austin Hamiltonian for what they call a model microtubule, Reimers et al conclude that strong and coherent Frohlich condensation are not feasible in microtubules. They also conclude that weak condensation in microtubules IS biologically feasible, and that Pokorny (2004) has experimentally shown weak Frohlich condensation in microtubules at 8 MHz. Asserting that the Penrose-Hameroff Orch OR model depends on strong/coherent Frohlich condensation, they emphatically conclude that Orch OR is untenable.

In response, I wish to make two points. The first is that weak Frohlich condensation at 8 MHz (with entanglement) may be sufficient for Orch OR. The second point is that Reimers et al have most definitely NOT shown that strong or coherent Frohlich condensation in microtubules is unfeasible. The model microtubule on which they base their Hamiltonian is not a microtubule structure, but a simple linear chain of oscillators.

Microtubules are cylindrical polymers of proteins called tubulin which self-assemble into hollow cylinders. The cylinder walls are hexagonal lattices of tubulin, slightly skewed so that helical windings around the microtubule follow Fibonacci geometry. Microtubules organize cell movement, mitosis/cell division, and synaptic plasticity in brain neurons. In the 1980s Hameroff and colleagues suggested microtubules were molecular computers, with conformational dipole states of individual tubulins in the hexagonal lattice playing the role of bits, interacting with neighbor tubulin states in microtubule (cellular) automata (Hameroff and Watt, 1982; Rasmussen et al, 1990).

Computers generally have an internal clocking frequency, and Hameroff suggested Frohlich coherence (weak condensation) as the synchronizing clock for updating microtubule automata. Simulations showed patterns of tubulin states on the cylindrical surface which repeat, interact and propagate. Simple networks of microtubule automata connected to others by microtubule-associated-proteins (MAPs) were able to learn, with specific locations of MAP attachment sites on the microtubule lattice being critical parameters.

In the 1990s Hameroff teamed with Sir Roger Penrose to develop a quantum computational model in microtubules called orchestrated objective reduction (Orch OR). The model suggested tubulins as quantum bits, or qubits which interact/compute with other tubulin qubits by entanglement. Specific mechanisms were suggested to avoid environmental decoherence including coherent phonon pumping as suggested by Frohlich (weak Frohlich condensation), encasement in actin gel, ordered water on the microtubule surface, and a Debye layer formed by negatively charged tubulin tail C-termini and positive counter-ions. Orch OR has been heavily criticized, for example on whether the proposed macroscopic quantum states can occur in warm and wet biology. Recent evidence has demonstrated quantum coherence does occur in warm biological systems (Engel et al 2007).

Reimers et al attempt to refute Orch OR by claiming that strong, or coherent Frohlich condensation necessary for Orch OR is disproven by their Hamiltonian. But their Hamiltonian doesnt model actual microtubules.

Reimers et al consider Frohlich excitations propagating as a random walk through tubulin oscillators. Collisions between so-called random walkers indicate the possibility of reinforcement, resonance, or coherence/condensation. For their model microtubule they first considered both a 1-dimensional linear string of tubulin oscillators, and a 2-dimensional lattice surface plane of tubulin oscillators.

They decided to study a 1-dimensional string because 2 random walkers confined to a line have a finite probability of hitting each other. In 2 dimensions, they reasoned, the hitting probability is zero because of the increased entropy that comes with the change in dimension.

This is a fundamental and profound error. Microtubules are neither 1-dimensional strings nor 2-dimensional lattice planes extending in all directions. Microtubules are cylinders with a wrap-around surface (which can be modeled as a torus). Signals traveling around/along microtubules inevitably collide with other signals. Fibonacci geometry insures collisions of the various spiral pathways in a microtubule. Microtubules are unique geometric lattice cylinders, under compression in living cells, suited to vibrational resonances. The Reimers claim is like plucking a loose string and expecting to hear a piano concerto.

In 1992 Samsonovich et al described a Hamiltonian which considered the proper cylindrical microtubule with Fibonacci geometry. Their results showed resonant nodes of phonon energy maxima and minima describing a super-lattice of repeating patterns. Moreover the super-lattice pattern of nodes matched precisely experimentally observed patterns of MAP attachments on the microtubule lattice, attachment patterns which regulate cellular architecture and function. They concluded that the particular periodical structure of microtubules resulted in a spectrum of Frohlich-like global phonon modes.

So we have two Hamiltonians purporting to search for Frohlich condensation in microtubules. One (Reimers et al) is based on a ridiculously crude approximation of microtubules as a linear string of oscillators and reveals no effects. The other (Samsonovich et al) is based on microtubule structure and Fibonacci geometry and demonstrates strong resonance and coherent patterns which match experimentally observed patterns of MAP attachments.

Maybe I missed something. But if Reimers et al based their purported refutation of Orch OR on such a lame model of a microtubule, they owe Orch OR, and the scientific community, a retraction in PNAS.

I do thank them for bringing to light the findings of Pokorny, demonstrating 8 MHz coherent excitations in microtubules.

This is indeed good news for Orch OR.

Stuart Hameroff

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