The Journal of Mind and Behavior
Summer and Autumn 2023, Volume 44, Numbers 3 and 4
Pages 135–146
ISSN 0271–0137

Consciousness from the Perspective of the QBIT Theory

Majid Beshkar

Tehran University of Medical Sciences

In this paper it is argued that qualia are physical. A conscious percept (or a quale) is a physical system that consists of many elements (called qubits) that are so highly (and intricately) ordered that they collectively form a unified whole which is more than and different from the sum of its parts. On the other hand, subliminal and preconscious percepts are physical systems whose elements are separate, disorganized, and incoherent. Furthermore, it is argued that the same fundamental physical mechanism that underlies the transition from fluidity to superfluidity (and the transition from conductivity to superconductivity), is also responsible for the transition from perception to something that could be called super-perception (or consciousness).

Keywords: consciousness, entropy, quantum coherence

One of the greatest challenges of science is to solve the problem of consciousness. Many theories have been developed to solve this problem, one of which is the QBIT theory of consciousness. Here, the word "QBIT" is an acronym made from the initial letters of quantum mechanics, biology, information theory, and thermodynamics. According to the QBIT theory, (1) the emergence of consciousness requires compression (or condensation) of information beyond a critical threshold (Beshkar, 2020, 2021), (2) when information–theoretic certainty of a system about a stimulus increases beyond a critical threshold, the observer becomes conscious of that stimulus (Beshkar, 2022), and (3) the brain generates consciousness by reducing the entropy of its internal representations below a critical threshold (Beshkar, 2023a). Different aspects of this theory have been explained extensively in previous papers. The emphasis of the present paper is on the idea that consciousness is a physical phenomenon, and qualia are made up of real physical elements that have undergone a kind of transformation which makes them seem unreal and non-physical in our classical world. At the end of the paper, I explain how the QBIT theory is related to one of the most promising theories in biological sciences, namely the free-energy principle.

Correspondence concerning this article should be addressed to Majid Beshkar, D.D.S., North Kargar Street, Tehran University of Medical Sciences, Tehran, Iran 1439955991. Email: majid.beshkar@gmail.com

Qualia as Physical Systems

Every physical system is composed of a number of elements. For example, water is a physical system composed of H_2O molecules; light is a physical system composed of photons; and the diamond is a physical system composed of carbon atoms.

Two parameters make a physical system unique. First, the nature of the elements that constitute the system; second, the organization of the elements within the system. Here, organization refers to the pattern of arrangement of the elements with respect to each other. What makes a system organized is the correlation (i.e., bond, link, or connection) that exists between the elements of the system.

A piece of ice and a piece of diamond are two distinct physical systems because the nature of the constituting elements is different in these systems. We cannot make water out of carbon atoms. The nature of the constituting elements is the primary factor that determines the nature (and unique properties) of a physical system. The way the elements of a physical system are organized with respect to each other is the second factor that determines the nature (and unique properties) of a physical system. One gram of ice and one gram of liquid water are two distinct physical systems, despite the fact that the nature and the number of the elements that constitute these two systems are the same. What makes ice different from liquid water is the organization of elements. The same is true about diamond and graphite: both are composed of the same elements (i.e., carbon atoms) but they are two very different systems because carbon atoms are organized differently in diamond compared to graphite. The same story holds true for light: a beam of ordinary light and a beam of laser light are both composed of the same elements (i.e., photons), but they are two distinct systems with very different properties. In a beam of laser light, photons are organized coherently with respect to each other; while in a beam of ordinary light, photons are relatively disorganized and incoherent.

According to the QBIT theory, a quale is a physical system in exactly the same sense that water, light, and diamond are physical systems. A quale is composed of a very special element, the identity of which is yet unknown. To create artificial consciousness (if possible at all), we need this very special element. We cannot create consciousness from photons, H_2O molecules, carbon atoms, etc.

To shed some light on these mysterious "elements of qualia," the QBIT theory has two conjectures: first, these elements are a product of biological organisms (in the same sense that insulin molecule is a product of biological organisms); second, these elements belong to the general class of physical entities known as qubits. I have no strong scientific evidence in support of these two conjectures, and I am completely open to the possibility that these conjectures might be wrong. Every attempt to solve a problem typically starts with some guesses. These two conjectures are among the basic guesses that I have adopted at the start of my exploration. Other explorers have adopted other basic conjectures, and it is the passage of time (and the accumulation of relevant experimental evidence) that will tell us which conjectures (and which path taken) have been appropriate.

An immediate consequence of the first conjecture is that, in the course of the evolution of the universe, the emergence of consciousness is a relatively recent event. Consciousness has emerged in the universe only after the emergence of life. Apparently, this does not mean that we cannot create artificial consciousness. In the same way that we can produce insulin in laboratories, we can, in principle, produce the elements of qualia in laboratory conditions. If we could organize an appropriate number of these artificial elements in exactly the same way that a human brain organizes them when it produces a quale, we have managed to create artificial consciousness.

In previous papers (Beshkar, 2022, 2023a) I have explained in detail why I think that the elements of qualia must be a kind of qubit. Briefly, qubits are carriers of quantum information, and quantum information is essential for the emergence of consciousness. In fact, the QBIT theory suggests that consciousness arises from entangled qubits. This is in accordance with an emerging idea in modern physics that everything in the universe (even light and gravity) arises from quantum information. This idea epitomizes in the famous phrase "it from qubit."

A system of qubits within the brain can realize a wide variety of distinct qualia depending (primarily) on how the qubits are organized with respect to each other. A red quale, a yellow quale, a sharp pain quale, a sour taste quale, a pungent odor quale, and all other kinds of qualia that our brain can generate are made up of the same elements. What makes a quale distinct from other qualia are the number of the constituent elements and the way these elements are linked to each other.

According to the QBIT theory, consciousness is the result of entropy minimization. As a sensory representation ascends the hierarchy of a sensory pathway, its entropy is gradually minimized until a maximally ordered, minimum-entropy representation is generated at the top of the hierarchy. Maximum order and minimum entropy are two characteristic features of macroscopic quantum systems that are in a coherent (or pure) state. For this reason, the QBIT theory proposes that the emergence of consciousness must be associated with the concept of macroscopic quantum coherence, a concept that underlies many exotic physical phenomena such as superfluidity and superconductivity.

The Perceptual Hierarchy

In response to an external stimulus, the brain generates a hierarchy of internal representations. These representations are also called percepts. Low-level representations are called subliminal percepts; mid-level representations are called preconscious percepts; and high-level representations are called conscious percepts (or qualia).

Percepts are transient information reservoirs. Each percept packs a lot of information in a format that can be easily used by different brain circuits which are in need of information to accomplish their own tasks. In this context, a percept could be considered as a resource for the brain. The more the information content of a percept, the more valuable the percept is. Subliminal percepts are minimally informative, preconscious percepts are moderately informative, and conscious percepts are maximally informative for the brain.

As explained in the previous section, a percept is a physical system. Any physical system (for example, a cube of ice) consists of a number of elements (for example, H_2O molecules) connected to each other via a kind of link (for example, the hydrogen bond). In the case of a percept, the elements are qubits and the link is quantum entanglement.

From an abstract perspective, a percept may be viewed as a graph (or network) consisting of qubits as vertices (or nodes) and inter-qubit entanglement as edges (or links). Figure 1 is a simple graphic illustration of some similarities and differences among subliminal, preconscious, and conscious percepts. One similarity among these three kinds of percepts is that the nature of the constituent elements is the same; all the three systems consist of a special kind of qubit. Another similarity is that the nature of the link between the constituent elements is the same; in all percepts, the elements are linked together by quantum entanglement. The three kinds of percepts differ from each other in terms of the number of elements, the number of links, and the pattern of linkage (entanglement) among elements. A subliminal percept contains only short-range links, a preconscious percept contains short-range and mid-range links, while a conscious percept contains many long-range links in addition to short- and mid-range links.

Subliminal, preconscious, and conscious percepts could be considered as different phases of the same system. A preconscious percept transforms into a conscious percept by means of a phase transition. The nature of this phase transition is, according to the QBIT theory, very similar to a special kind of phase transition which theoretical physics has predicted to occur in nature. Although we have not yet observed this kind of phase transition occurring naturally, scientists have experimentally demonstrated it in laboratory conditions (Ornes, 2017). This special kind of phase transition is what transforms a normal fluid to a superfluid, and a normal conductor to a superconductor, and a gas of atoms to a Bose–Einstein condensate.

Superfluidity

A superfluid is a special kind of fluid that has odd properties. Much of its oddness is due to the fact that the atoms that constitute a superfluid do not collide with each other; they move in unison, like the movement of soldiers in a military parade. The harmony and coherence between the elements of a superfluid allow it to do things that normal fluids cannot.

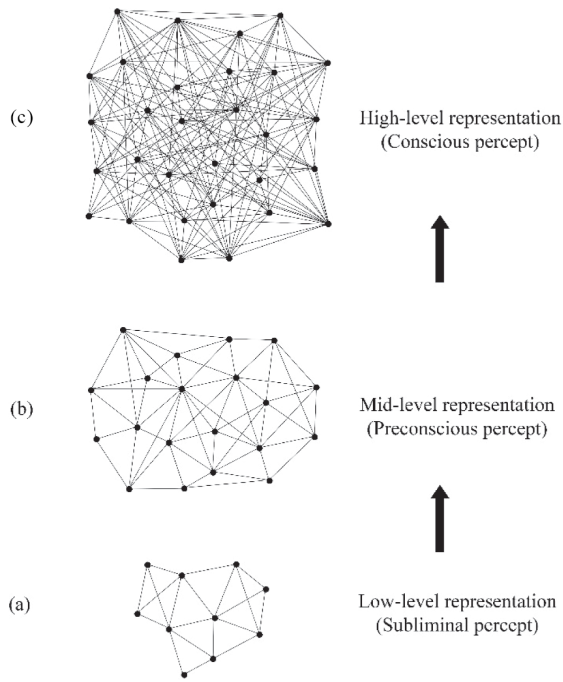

Figure 1: A graph is a collection of vertices connected by edges. This figure shows three different graphs in which vertices are depicted as circles and edges are depicted as lines, (a) a low-level representation (also called a subliminal percept) depicted as a graph with 10 vertices and 20 edges; (b) a mid-level representation (also called a preconscious percept) depicted as a graph with 20 vertices and 60 edges; and (c) a high-level representation (also called a conscious percept) depicted as a graph with 30 vertices and 180 edges.

A superfluid has zero viscosity, which means that it flows without friction and thus without any loss of kinetic energy (Pitaevskii and Stringari, 2016, p. 65). A superfluid can enter and move through microscopic cracks that are as narrow as 100 nanometers (Tsuneto, 1998, p. 4). This is impossible for a normal fluid. If you put a superfluid in a cup, it gradually escapes the cup by climbing up and over the sides of the cup (Huang, 2017, p. 8). If you set down a cup with a normal fluid circulating in it, you will see that the fluid will stop moving after a while. This is due to the fact that atoms in the swirling fluid will collide with each other (as well as with the walls of the cup) and thus will gradually slow down and stop moving. But if you do the same with a superfluid, you will see that the fluid continues to rotate.

Superfluidity can emerge only in certain systems under special conditions. Not all liquids can become superfluid. A limiting factor in this context is that the liquid must remain fluid at extremely low temperatures (near absolute zero), without transforming to a solid phase. A liquid that freezes at a temperature near absolute zero cannot become a superfluid.

When a liquid is cooled down, the slight attraction that normally exists between its constituting elements (for example, atoms or molecules) begins to overcome thermal fluctuations. As a consequence, the atoms or molecules start to settle into a "regular order," giving rise to the formation of a solid. But in order for a liquid to become a superfluid, it must avoid being trapped in this "regular order" and instead keep continuing its way towards a much more intricate order as the temperature is reduced. This intricate order has a specific name in modern physics: "macroscopic quantum coherence."

One of the few systems in which superfluidity can emerge is a system that consists of helium-4 (^4He) atoms. At room temperature and ambient pressure, helium-4 is a gas. It transforms to liquid at an extremely low temperature of 4.15 kelvin. When liquid helium-4 is cooled below a critical temperature of 2.17 K, a thermodynamic phase transition occurs in the system and a fraction of the ^4He atoms condense to form a unified whole and become a superfluid (Allen and Misener, 1938; Kapitza, 1938). Those atoms that are not included in the condensate behave like a normal fluid, and the whole system can be explained by a two-fluid model, in which the superfluid and the normal fluid are two interpenetrating fluids with radically different properties (Huang, 2017, p. 5). This superfluid fraction increases as the temperature goes further down towards absolute zero.

In addition to ^4He, helium has another stable isotope named helium-3 (^3He). Helium-3 can also become superfluid at a critical temperature of 0.0027 K (Osheroff et al., 1972). While helium-4 has only one known superfluid phase, helium-3 has three different superfluid phases (A, A1, and B) with rather different properties (Tsuneto, 1998, p. 128). It is remarkable that the A1 phase can emerge only in a magnetic field.

Superconductivity

Superconductivity is a physical phenomenon characterized by complete disappearance of electrical resistance. Electricity can flow through a superconductor without encountering any resistance and thus without any loss to heat. This means that a superconductor can transmit electrical energy with 100% efficiency (Hamlin, 2019).

Unlike superfluidity that has been experimentally observed in only a very few systems, superconductivity has been demonstrated to emerge in many different systems. Almost half the elements in the periodic table can become superconductors, although at extremely low temperatures (Armitage, 2019). For example, mercury (Hg) can become a superconductor if cooled below a critical temperature

(T_C) of 4 K. However, superconductivity is not a phenomenon that exclusively belongs to the ultracold regime. In fact, theoretical physics has predicted that superconductivity could emerge even at room temperature (295 K) in physical systems that are endowed with certain favorable properties such as lattice vibrations at high frequencies (Drozdov et al., 2019).

Over the past century, the record for high temperature superconductivity has progressed (Hamlin, 2019, p. 491). For example, Schilling et al. (1993) discovered superconductivity at a T_C of 133 K in an Hg–Ba–Ca–Cu–O system at ambient pressure. Drozdov et al. (2015) discovered superconductivity at a T_C of 203 K in a system consisting of hydrogen sulfide (H_3S) at a pressure that was nearly 2 million times Earth's atmospheric pressure. Drozdov et al. (2019) discovered superconductivity at a T_C of 250 K in a system consisting of lanthanum hydride compounds (LaH_{10}) at a pressure of about 170 gigapascals. Finally, Dasenbrock–Gammon et al. (2023) discovered superconductivity in a lutetium hydride system at a T_C of 294 K at 10 kilobar, that is, superconductivity at room temperature and near-ambient pressure.

Bose–Einstein Condensation

Bose–Einstein condensation is a thermodynamic phase transition that gives rise to the emergence of a weird state of matter called the Bose–Einstein condensate (BEC). Imagine a dilute gas consisting of many atoms that move freely and separately in all possible directions. In this system each atom has its own position, velocity, and direction of motion. In other words, each atom is in its own quantum state and its behavior can be described by its own wavefunction. When Bose–Einstein condensation occurs in such a disordered system, atoms lose their individuality, enter into the same quantum state, collectively behave like a single superatom whose behavior can be described by the same wavefunction (Chu, 2002). This super atom is called a BEC.

Bose–Einstein condensates are very fragile, and have not yet been observed naturally on Earth. However, they have been created in laboratory conditions from a variety of different kinds of atoms, molecules, and quasiparticles. A Bose–Einstein condensate can be created by either decreasing the temperature or increasing the density of the particles in a system (Demokritov et al., 2006). Typically, BECs of real particles (including atoms and molecules) are created by reducing the temperature to near absolute zero, while BECs of quasiparticles are created by injecting more quasiparticles into the system thus increasing the density of the system (Schneider et al., 2020). Below a critical temperature or above a critical density, Bose–Einstein condensation takes place in the system, and the system starts to behave differently (Kasprzak et al., 2006).

The critical temperature for the creation of a BEC from a collection of identical particles is inversely proportional to the mass of the particles. For particles with smaller mass, the critical temperature at which condensation occurs is higher (Snoke, 2006, p. 404). Bose–Einstein condensation of atoms and molecules occurs at extremely low temperatures because of the relatively large mass of even the lightest atoms and molecules (Bugrij and Loktev, 2008). For example, $T_C = 170$ nanokelvin for rubidium atoms (Anderson et al., 1995); $T_C = 2$ microkelvin for sodium atoms (Davis et al., 1995); $T_C = 160$ nanokelvin for cesium atoms (Weber et al., 2003); and $T_C = 600$ nanokelvin for lithium molecules (Li_2) [Zwierlein et al., 2003].

Compared to atoms and molecules, quasiparticles (for example, magnons or exciton–polaritons) have very small mass and, therefore, quasiparticle BECs can be created at higher temperatures. The effective mass of an exciton–polariton is typically only 10^{-11} times the mass of an atom (Plumhof et al., 2014). Therefore, in principle, exciton–polariton BEC can be created at a temperature that is many orders of magnitude higher than that of atomic BECs. Kasprzak et al. (2006) created a BEC of exciton–polaritons at a temperature of 19 K, and Plumhof et al. (2014) created a BEC of exciton–polaritons in a polymer at room temperature. Demokritov et al. (2006) also reported creating a BEC of magnons at room temperature.

Super-Effects

Superfluidity, superconductivity, and Bose–Einstein condensation are different members of the same family: the family of super-effects. The QBIT theory suggests that consciousness (which could be thought of as super-perception) also belongs to this family of phenomena.

The members of this family share some common features. First of all, it should be emphasized that, at a fundamental level, all these phenomena can only be explained by resorting to quantum mechanics. In a BEC, all atoms occupy the same position in space, something that is not allowed in the realm of classical physics. This can be explained only by wave–particle duality, a basic principle of quantum mechanics.

A characteristic feature of Bose–Einstein condensation is the emergence of a macroscopic coherent state in a system that is incoherent (Schneider et al., 2020, p. 457). The essence of Bose–Einstein condensation is the spontaneous emergence of coherence. Snoke (2006, p. 403) argues that "As spontaneous coherence is so essential to the phenomenon of Bose–Einstein condensation, to prove that one has a condensate, one must demonstrate two things: first, that there is coherence, and second, that this coherence is spontaneous."

The emergence of macroscopic quantum coherence (or a coherent quantum object) out of an incoherent, chaotic system is not something that is restricted only to Bose–Einstein condensation: it is a common feature of all super-effects. Superconductivity, for example, is also a macroscopic quantum phenomenon associated with spontaneous emergence of coherence. Superconductivity is characterized by the condensation of the electrons into a macroscopically coherent matter-wave. Therefore, superconductivity could be regarded as the matter-wave counterpart of laser light, which is essentially a coherent form of light (Fossheim and Sudbø, 2004, p. 90). The same basic mechanism underlies superfluidity (Pitaevskii and Stringari, 2016, p. 273) as well as super-perception (Beshkar, 2023b). Bose–Einstein condensates, superfluids, superconductors, and super-percepts (i.e., qualia) are all coherent physical entities. Deng et al. (2010, p. 1515) contend that "In BEC, a macroscopic number of particles occupy a single-quantum state and manifest quantum correlations on the macroscopic scale." Likewise, in a super-percept, a macroscopic number of brain qubits occupy a single-quantum state and manifest quantum correlations (in the form of entanglement) on a macroscopic scale. This is why the QBIT theory suggests that consciousness arises from entangled qubits (Beshkar, 2022).

In addition to spontaneous coherence, another feature common to all the members of the super-effects family is entropy minimization. Tsuneto (1998, p. 2) argues that "Since entropy is released as the temperature is lowered through T_C the superconducting (superfluid) state has less entropy than the extrapolated normal state at the same temperature. In other words, the superconducting phase is more ordered than the normal phase." In a previous paper (Beshkar, 2023a), I have explained, in detail, how (and why) the emergence of consciousness is associated with a decrease in entropy.

Entropy minimization is a central theme in the free-energy principle, a theoretical framework that successfully explains a range of biological phenomena. The success of the free-energy principle has motivated me to investigate whether or not the QBIT theory is consistent with the free-energy principle.

The Free-Energy Principle

The QBIT theory is consistent with the free-energy principle. The free-energy principle is, of course, a more universal and rigorous theoretical framework compared to the QBIT theory. The explanatory power of the free-energy principle is much greater than the QBIT theory. The free-energy principle applies to all adaptive systems that resist disorder, of which the brain is just one. Even when applied to the brain, the free-energy principle can explain not just consciousness but a wide range of brain phenomena and functions including action selection, perceptual inference, and learning.

According to the free-energy principle, the brain is constantly working to minimize its free energy (Friston, 2010). Minimizing free energy corresponds to minimizing entropy and uncertainty. Therefore, according to the free-energy principle, the brain is constantly working to minimize its entropy and uncertainty (Friston et al., 2006). From the perspective of the QBIT theory, the emergence of consciousness could be regarded as a consequence of free-energy minimization.

Consciousness emerges when the brain succeeds in decreasing the amount of free energy associated with its internal representations below a critical threshold. That threshold lies at an extreme end of the spectrum of free energy. When the free energy (and hence the entropy) of a representation decreases below the critical threshold, that representation becomes a conscious representation (a.k.a. a quale). Therefore, a quale could be regarded as a product of extreme free-energy minimization.

If we admit that entropy corresponds to disorder (and information corresponds to order), it is plausible to suggest that minimizing the free energy (and thus the entropy) of a representation corresponds to minimizing the disorder, and thus maximizing the order as well as the information content of that representation. When the process of free-energy minimization progresses, a maximally ordered (and thus maximally informative) representation is generated. Such a representation is called a quale, and as long as the brain has a quale, it is conscious.

According to the QBIT theory, the process of free-energy minimization could be understood as the process of converting free energy to bound energy. In this respect, free energy refers to the energy of a free element. The more the number of free elements in a system, the more the free energy of the system. We can reduce the free energy of a system by reducing the number of free elements of the system. We can reduce the number of free elements of a system by bonding (linking, correlating, or entangling) the free elements together. Therefore, we can reduce the free energy of a system by bonding the elements of the system together. Bonding the elements together is synonymous with increasing the correlation between the elements. Thus, we can reduce the free energy of a system by increasing the correlation between the elements of the system. The more the amount of correlation between the elements of a system, the less the amount of free energy of the system.

The idea that binding free energy corresponds to free-energy minimization was previously hinted at by Solms (2019) in his attempt to apply the free-energy principle to the hard problem of consciousness. Solms writes that "self-organizing systems generate a type of work that binds free energy" (2019, p. 10). He mentions that "For a system to resist entropy, three conditions must be met: (i) There must be a boundary which separates the internal and external states of the system [....] (ii) There must be a mechanism which registers the influence of dissipative external forces — i.e. the free energy. Let's call this mechanism the "sensory states" of the system. (iii) There must be a mechanism which counteracts these dissipative forces — i.e. which binds the free energy" (2019, p. 9).

In accordance with the free-energy principle, the QBIT theory suggests that the brain constantly works on its current state to bind the state's elements together (as tightly as possible) in order to reduce the free energy (and thus the disorder or entropy) of its state. When the state's elements become maximally correlated (in other words, maximally integrated or entangled), they collectively form a unified whole that is more than (and different from) the sum of its elements. This maximally correlated and integrated state is what the QBIT theory calls a conscious state.

Before closing this section, I would like to emphasize that "free energy" in the free-energy principle is an information–theoretic measure, not a thermodynamic one. This information–theoretic (variational) free energy should not be regarded as the counterpart of thermodynamic free energy. As mentioned by Friston (2010, p. 128), "This (variational) free-energy construct was introduced into statistical physics to convert difficult probability-density integration problems into easier optimization problems. It is an information theoretic quantity (like surprise), as opposed to a thermodynamic quantity."

The QBIT theory suggests that if we would like to translate the term "free energy" from the language of information theory into the language of thermodynamics, the best option is the term "disorganized energy." Free means disorganized, while integrated or correlated means organized. With this in mind, the principle of free-energy minimization could also be called the principle of organization maximization.

References

Allen, J. F., and Misener, A. D. (1938). Flow phenomena in liquid helium II. *Nature, 142,* 643–644.

Anderson, M. H., Ensher, J. R., Matthews, M. R., Wieman, C. E., and Cornell, E. A. (1995). Observation of Bose–Einstein condensation in a dilute atomic vapor. *Science, 269,* 198–201.

Armitage, N. P. (2019). Superconductivity mystery turns 25. *Nature, 576,* 386–387.

Beshkar, M. (2020). The QBIT theory of consciousness. *Integrative Psychological and Behavioral Science, 54,* 752–770. doi: 10.1007/s12124-020-09528-1

Beshkar, M. (2021). The QBIT theory of consciousness. In P. Dennison (Ed.), *Perspectives on consciousness* (pp. 99–149). Nova Science.

Beshkar, M. (2022). The QBIT theory: Consciousness from entangled qubits. *Integrative Psychological and Behavioral Science*. doi: 10.1007/s12124-022-09745-w

Beshkar, M. (2023a). The QBIT theory of consciousness: Entropy and qualia. *Integrative Psychological and Behavioral Science, 57,* 937–949. doi: 10.1007/s12124-022-09684-6

Beshkar, M. (2023b, in press). The QBIT theory of consciousness: Information, correlation, and coherence. *Integrative Psychological and Behavioral Science*. doi: 10.1007/s12124-023-09784-x

Bugrij, A. I., and Loktev, V. M. (2008). On the particularities of Bose–Einstein condensation of quasiparticles. *Low Temperature Physics, 34,* 992–996.

Chu, S. (2002) Cold atoms and quantum control. *Nature, 416,* 206–210.

Dasenbrock–Gammon, N., Snider, E., McBride, R. et al. (2023). Evidence of near-ambient superconductivity in a N-doped lutetium hydride. *Nature, 615,* 244–250.

Davis, K. B., Mewes, M., Andrews, M. R., van Druten, N. J., Durfee, D. S., Kurn, D. M., and Ketterle, W. (1995). Bose–Einstein condensation in a gas of sodium atoms. *Physical Review Letters, 75,* 3969–3973.

Demokritov, S. O., Demidov, V. E., Dzyapko, O. et al. (2006). Bose–Einstein condensation of quasi-equilibrium magnons at room temperature under pumping. *Nature, 443,* 430–433.

Deng, H., Haug, H., and Yamamoto, Y. (2010). Exciton–polariton Bose–Einstein condensation. *Reviews of Modern Physics, 82,* 1489–1537.

Drozdov, A. P., Eremets, M. I., Troyan, I. A., Ksenofontov, V., and Shylin, S. I. (2015). Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system. *Nature, 525,* 73–76.

Drozdov, A. P., Kong, P. P., Minkov, V. S., Besedin, S. P., Kuzovnikov, M. A., Mozaffari, S. et al. (2019). Superconductivity at 250 K in lanthanum hydride under high pressures. *Nature, 569,* 528–531.

Fossheim, K., and Sudbø, A. (2004). *Superconductivity: Physics and applications*. John Wiley & Sons.
Friston, K. (2010). The free-energy principle: A unified brain theory? *Nature Reviews Neuroscience, 11,* 127–138.
Friston, K., Kilner J., and Harrison, L. (2006). A free energy principle for the brain. *Journal of Physiology – Paris, 100,* 70–87.
Hamlin, J. J. (2019). Superconductivity near room temperature. *Nature, 569,* 491–492.
Huang, K. (2017). *A superfluid universe*. World Scientific Publishing
Kapitza, P. (1938). Viscosity of liquid helium below the λ-point. *Nature, 141,* 74.
Kasprzak, J., Richard, M., Kundermann. S. et al. (2006). Bose–Einstein condensation of exciton polaritons. *Nature, 443,* 409–414.
Ornes, S. (2017). How Bose–Einstein condensates keep revealing weird physics. *Proceedings of the National Academy of Sciences, 114,* 5766–5768.
Osheroff, D. D., Richardson, R. C., and Lee, D. M. (1972). Evidence for a new phase of solid He^3. *Physical Review Letters, 28,* 885–888.
Pitaevskii, L., and Stringari, S. (2016). *Bose–Einstein condensation and superfluidity*. Oxford University Press.
Plumhof, J. D., Stöferle, T., Mai, L., Scherf, U., and Mahrt, R. F. (2014). Room-temperature Bose–Einstein condensation of cavity exciton–polaritons in a polymer. *Nature Materials, 13,* 247–252.
Schilling, A., Cantoni, M., Guo, J. D., and Ott, H. R. (1993). Superconductivity above 130 K in the Hg–Ba–Ca–Cu–O system. *Nature, 363,* 56–58.
Schneider, M., Brächer, T., Breitbach, D. et al. (2020). Bose–Einstein condensation of quasiparticles by rapid cooling. *Nature Nanotechnology, 15,* 457–461.
Snoke, D. (2006). Coherent questions. *Nature, 443,* 403–404.
Solms, M. (2019). The hard problem of consciousness and the free energy principle. *Frontiers in Psychology, 9,* 2714.
Tsuneto, T. (1998). *Superconductivity and superfluidity*. Cambridge University Press
Weber, T., Herbig, J., Mark, M., Nägerl, H.-C., and Grimm. R. (2003). Bose–Einstein condensation of cesium. *Science, 299,* 232–235.
Zwierlein, M. W., Stan, C. A., Schunck, C. H., Raupach, S. M. F., Gupta, S., Hadzibabic, Z., and Ketterle, W. (2003). Observation of Bose–Einstein condensation of molecules. *Physical Review Letters, 91,* 250401.