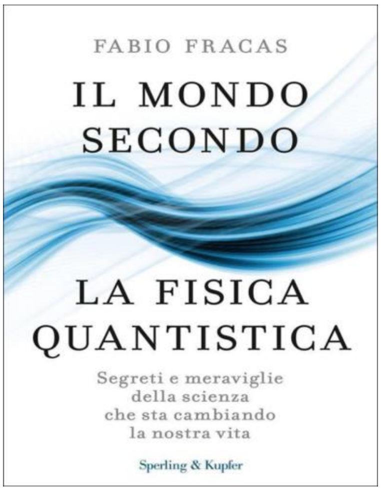
THE WORLD ACCORDING TO QUANTUM PHYSICS

by

Fabio Fracas



Quantum Physics and Consciousness

The possible contribution of quantum physics to the study of consciousness can be divided into two different areas:

1. The theory that at the basis of consciousness and the "mind" there are quantum physical mechanisms and quantum-type properties;
2. The possibility that the paradigms and logics of quantum physics allow new interpretations of the functions of thought and consciousness.

The first theory has yet to be investigated. Although there is some recent evidence implying its validity, a quantum physiology of consciousness has not been definitively confirmed.
The second theory does not require quantum phenomena in neurones. This latter is an essentially epistemological argument: the quantum approach actually constitutes a challenge to the classical structure of thought, and to the constitutional inability of materialism to include consciousness and the psyche in the world.

A premise

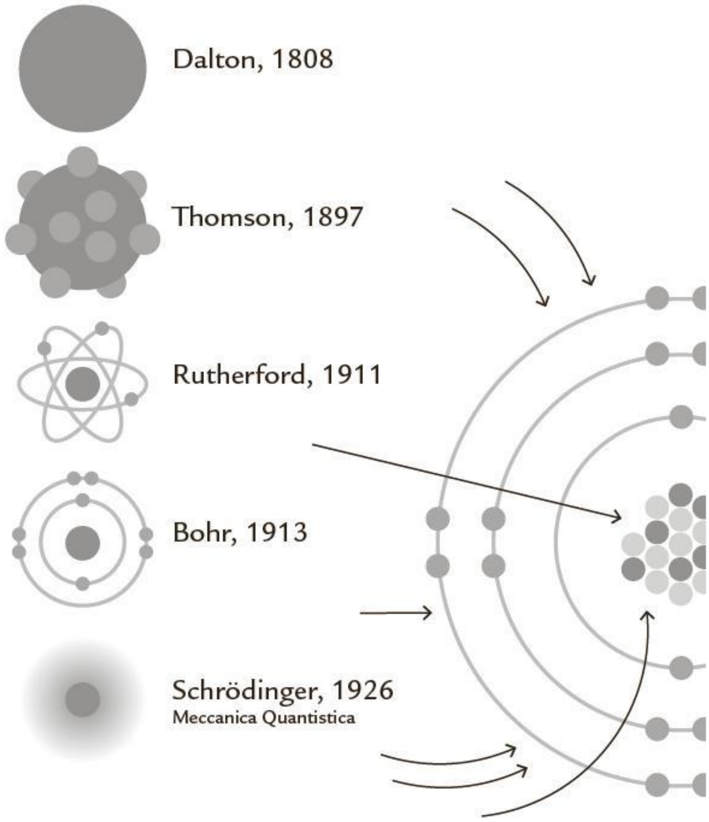
The problem of possible quantum aspects of consciousness is difficult to face because the physical size of phenomena commonly studied in biology renders them well-suited to the application of classical terminology.
This does not exclude the possible role of quantum phenomena in physiological and pathological processes, even if the study of these processes is complicated for a variety of reasons.

Criticisms

1. Studies of a biological nature have to be conducted on living beings, with all the associated experimental limitations of this.
2. The brain is an extremely complex organ, both anatomically and functionally, and its physiology is only partially understood. These reasons make it even more difficult to isolate and identify the possible roles of single quantum components.
3. The critical problem remains understanding the relationship between the quantum world and the classical world: whether or not what happens at an atomic and subatomic level according to the laws of

quantum physics translates into a certain behaviour of neurons and cerebral circuits (if and how).

Fundamental concepts



Evolution of the atomic model

Collapse of the wave function: we know that each quantum particle, because of the wave-particle duality, carries an associated wave function. When a particle moves about freely unobserved, it is as if it “dissolves” into overlapping probability waves. In practice, that particle is simultaneously potentially present in multiple different places of a region in space. This concept, for example, is inherent in the definition of electron orbits.
If, however, we perform a measurement, experimentally we obtain a single result rather than a series of possibilities. It is as if the associated wave function “collapses” the instant it is measured, allowing us to identify the particular particle.
Decoherence: from another point of view, considering the interaction between the quantum system and external environment, we can also say that the wave function evolves in time only towards some of the possible states – those that are most probable and not overlapping. In other words, the states coinciding with the values defined by measurement.
To explain why this happens we need to introduce the concept of decoherence. If we consider physical states of particles as if they were non-isolated (simultaneously

present), the wave function evolves such that the probability of superposed states materializing is close to zero. In this way, the only possible states – those actually measured – will be non-superposed.
All of this, however, is only valid for quantum systems to which the **Principle of Superposition** applies, which was formulated by Erwin Schrödinger in 1926 and can be simplified thus: two or more quantum states can be superposed to form another valid quantum state.
Similarly, each quantum state can be represented as the superposition of two and/or more quantum states. Even though it may seem an obvious statement, the Principle of Superposition cannot be applied to macroscopic systems such as those that comprise our reality. Consequently, the concepts of collapse of wave function and decoherence also lose their significance outside the atomic or subatomic scale.

Miscellaneous Thoughts

Given the above, it is necessary to note that if the innermost structure of matter at the atomic and subatomic level is quantum in nature, there is no reason in principle to believe without question that phenomena governed by quantum mechanics cannot also take place in living beings and their physiological environments.
The problem really is if these phenomena are biologically significant; namely, if they are able to influence biological functions to the point where they can be better understood by applied the laws and paradigms of quantum physics.

Biological quantum mechanisms

In the biological world there is a role for quantum mechanisms (Lambert et al., 2013; Bordonaro & Ogryzko, 2013; Brookes, 2017; Melkikh & Khrennikov, 2015); the best known are:

1. Photosynthesis in bacteria and plants;
2. Olfaction;
3. Orientation in migratory species and in some non-migratory animals.

In plant and bacterial photosynthesis light energy, as photons, is absorbed by protein antennas of chlorosomes and results in electronic excitation. From there it is taken to pigment-protein complexes in the reaction centre where it is converted to a more stable chemical energy via species-specific mechanisms.
They therefore behave like quantum heat machines able to convert high-energy photons into a flux of low-entropy electrons (Dorfman et al., 2013). These transport and conversion systems are very efficient, able to maintain quantum coherence and so transfer the excitation energy of almost all the absorbed photons. These

coherence phenomena occur at environmental temperatures and are compatible with biological life.
Migratory birds are equipped with specific photoreceptors in the eye which can detect the magnetic field angle and also used as magnetic compasses (Gould, 2015; Ritz et al., 2000), allowing establishment of both navigational direction and the bird's relative position. This mechanism, dependent on the wavelength of light, distinguishes the poles from the equator rather than north from south (Heyers et al., 2017), whereas the receptors appear to come in two types: a photosensitive retinal one linked to the compass system, and the other associated with the ophthalmic branch of the trigeminal nerve and sensitive to variations in magnetic field (Beason, 2005; Mouritsen & Hore, 2012).
The light-dependent magnetoreception of the avian retina is probably mediated by the retina's cryptochromes (flavoproteins sensitive to blue light) and is sensitive to light polarization (Muheim et al., 2016).
On the other hand, the magnetic compass is based on chemical processes involving free radical spin, particularly their singlet or triplet states. After activation by light, the cryptochromes enter a redox cycle, forming radical pairs generated during photo-reduction, followed by light-independent re-oxidation; the latter allows orientation in during phases of darkness (Wiltschko et al., 2016).
The magnetic compass has also been described in reptiles, amphibians, crustaceans, and some insects such as Drosophila Melanogaster (fruitfly), flies and cockroaches.
Amphibians are able to use the compass during the day and in night-time conditions but not in total darkness (Phillips et al., 2010). In vitro experiments on purified cryptochromes from Drosophila show a photo-induced electron transfer from a magnetic field variation of a few milliTesla, but the researchers suggest that the in vivo sensitivity to the magnetic field could be significantly greater (Sheppard et al., 2017).
Some aggregates of photo-sensitive bacteria, when stimulated by a laser, show quantum entanglement properties (Melkikh & Khrennikov, 2015). The tunnel effect seems to be involved in biological processes: this is a quantum-mechanical effect which is not predicted by classical physics, and allows particles to overcome energy barriers that would normally be insurmountable. Tunnelling is intimately connected to wave-particle superposition, Heisenberg's Uncertainty Principle, and the resolution of Schrödinger's wave function.
Tunnelling allows a path long enough for enzyme catalysis and redox reactions in the proteins of respiratory chains (the redox centres of which are separated by 15-30 Å), while electron transfer along codified paths of protein structures and intermediate sites plays an important role in respiration and photosynthesis, allowing their function and, above all, their high efficiency (Lambert et al., 2010, 2013).

Quantum theories of consciousness

Theories relating to single and specific neuronal quantum-mechanical effects:

1. Tunnelling phenomena in pre-synaptic neurotransmitter release (Beck & Eccles, 1992; Beck, 1996);
2. Spin in membranes and cellular proteins (Hu & Wu, 2004);
3. Quantum-mechanical phenomena in dendrites of calcium channels and N-methyl-D-aspartate receptors (Woolf, 1999);
4. The superposition state and subsequent objective reduction (OR) in neuronal microtubules (Hameroff, 2001, Hameroff & Penrose, 2014).

Psychological theories of Jungian origin are subdivided in three different ways, and supposing:

1. A parallel between the unconscious/conscious relationship and quantum-mechanical/classical properties (Galli Carminati & Martin, 2008; Martin et al., 2010);
2. A relationship between the collective unconscious and Everett's interpretation of the multiverse (Mensky, 2013);
3. A relationship between quantum-mechanical events and synchronicity (Keutzer, 1984; Germine, 1991).

Theories on the non-locality of consciousness, both in terms of entanglement between different individuals, and an actual extracerebral consciousness (Taneichi, 2015; Thaheld, 2004b, 2005, 2010; Wackermann et al., 2003; Walach & Romer, 2000; Walach, 2005).

The Orch-Or Theory

The Orch-Or Theory – originally the Or Theory – was conceived in 1989 as an intuition with no experimental support.
In *The Emperor's New Mind,* Roger Penrose proposed the theory that brain function is not guided by logical or formal algorithms that belong to classical physics, but rather by quantum processes connected to wave function collapse. At the same time, Penrose also proposed a new definition of "objective reduction" to indicate how the moment of collapse depends on concrete factors linked to the relationship between the mass and energy of the objects involved in the process. Regarding consciousness, Penrose's objective reduction suggested that determination of which states underwent collapse was random and was influenced by space-time geometry.

When the theory was first formulated (considered whimsical by many researchers), the American anaesthetist Stuart Hameroff gave it a decisive contribution. He suggested to Penrose that probable neurological sites active in quantum processes are the microtubules in neurons. In fact, microtubules are a structural component of the neuronal cytoskeleton, and are the main component of the long-distance neuronal transport apparatus. This characteristic, based on Hameroff's studies, makes them the ideal candidate for the crystallization of Penrose's intuition.
From the combined studies of these two scientists, in 1994 *Shadows of the Mind* was published, containing the current definition of the Orch-Or Theory. In it, the term "orchestrated" refers to the reciprocal influence microtubules exert on each other, like a well-directed orchestra, while they are simultaneously influenced by the classical activities of neuronal synapses.
Penrose and Hameroff's theory has been refuted by the Swedish physicist and cosmologist Max Erik Tegmark, who calculated the time required for both normal neuronal discharge and signal transport in microtubules, discovering it to be slower than decoherence time by at least 10 billion times. Such a huge difference could result in moving consciousness processes from the quantum scale to the classical scale.
At the moment there is only one study showing the presence of quantum activity within microtubules but it is not considered sufficient to support a complete Quantum Theory of Consciousness in the way the Orch-Or is presented.
This study – performed in 2013 by a team led by Anirban Bandyopadhyay of the National Institute of Science and Materials of Tsukuba, Japan – has however provided an interesting debate about the Penrose/Hameroff theory by suggesting, furthermore, that the electromagnetic behaviour of microtubules could make the similar to, from a functional point of view, to neural memory chips.
Even Tegmark's results have been criticised. The dispute refers to Tegmark basing his calculations on the model of simple ion diffusion across a permeable membrane, instead of considering the real biological structure of cellular ion channels, including their selectivity and high efficiency.
A recent study by Vahid Salari on a diffusion model closer to actual cellular ion channels has estimated the decoherence times to be in the order of 10^{-12} seconds. A figure very similar to Tegmark's and that, even if not directly compatible with neuronal physiology times, is long enough to leave a trace with a wave function that is highly delocalized in the ion channel's entire structure.
In this way, even if microtubules are not themselves the seat of consciousness, quantum processes that could take place within them may modify baseline conditions from which the process of consciousness develops, conditioning its creation and content.
We need to also consider that microtubules, as was recently discovered, are directly implicated in memory and learning, and are altered in the early stages of dementia

and Alzheimer's. These two aspects suggest a possible role of microtubules in consciousness. This role, if confirmed, would open interesting avenues of research for new treatments of cognitive disorders.

A Quantum model of the mind

The quantum physics paradigm, although counterintuitive, seems to be better than the classic approach at explaining some cognitive aspects, such as the probability of making decisions in uncertain or conflicting situations (Bruza et al., 2015; Gonzalez & Lebiere, 2013; Wang et al., 2013).
Classical models of probability laws certainly remain valid, but in these specific situations seem to be rather weak, while models derived from quantum physics are more reliable and are better able to interpret underlying decisional processes.
The model of quantum cognition, which originated from the theory of probability developed in quantum physics, does not require any physical quantum mechanical event in the brain. Its main advantage is that it works even in situations in which there is no logical link between events, and results are conditioned by the order in which they occur.
This occurs when a choice is required between two incompatible events in uncertain conditions, or rather, such that they cannot be considered simultaneously and their understanding necessitates a new point of view.
Studies that have been conducted show that the quantum approach highly conforms to reality. Wang et al (2014) analyzed in detail the results of three different American surveys that asked the same questions in reverse order to two random groups of people.

1. The first survey asked a group if Bill Clinton was honest and trustworthy, and then if Al Gore was honest and trustworthy; the second group was asked first if Al Gore was honest and trustworthy, and then the same about Clinton.
2. The second survey asked in the same manner if whites hate blacks, and if blacks hate whites.
3. The third survey likewise asked whether or not Pete Rose should be included in the baseball Hall of Fame, and whether or not Joe Jackson should be in the same Hall of Fame.

The results showed a significant difference in the two groups of each survey, with respect to the question order. The discrepancy indicates a large variation between reasoning and the classical theory of probability, and has been called the conjunction fallacy. It is also possible, however, that it shows a different quantum-origin probabilistic concept. Therefore, rather than it being irrational, it probably reflects a different interpretation of rationality (Pothos et al., 2017): in formulating the second answer, the first one is taken into account along with eventualities that

may arise from previous information and decisions, resulting in the dynamic modification of decisions.
The quantum approach has been applied successfully, apart from decision analyses, to a large range of cognitive phenomena, such as perception, memory, the subconscious, and games (Atmanspacher & Filk, 2013; Khrennikov, 2015; Pothos & Busemeyer, 2009; Nelson et al., 2013).

General quantum model

To conclude this brief overview, where each topic can be greatly expanded, there remains one more question to ask. If quantum processes, in their broader sense, permeate the nature of matter itself and the structure of thought and the brain – even in its material and biological aspects – can they possibly also be reflected at an even "broader" level, on a cosmological scale?