International Journal of Psychophysiology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Quantum neurophysics: From non-living matter to quantum neurobiology and psychopathology

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ARTICLE INFO

Available online xxxx

Keywords:
Quantum physics
Measurement problem
Consciousness
Quantum biology
Quantum neurobiology
Psychopathology

ABSTRACT

The concepts of quantum brain, quantum mind and quantum consciousness have been increasingly gaining currency in recent years, both in scientific papers and in the popular press. In fact, the concept of the quantum brain is a general framework. Included in it are basically four main sub-headings. These are often incorrectly used interchangeably. The first of these and the one which started the quantum mind/consciousness debate was the place of consciousness in the problem of measurement in quantum mechanics. Debate on the problem of quantum measurement and about the place of the conscious observer has lasted almost a century. One solution to this problem is that the participation of a conscious observer in the experiment will radically change our understanding of the universe and our relationship with the outside world. The second topic is that of quantum biology. This topic has become a popular field of research, especially in the last decade. It concerns whether or not the rules of quantum physics operate in biological structures. It has been shown in the latest research on photo-synthesis, the sense of smell and magnetic direction finding in animals that the laws of quantum physics may operate in warm-wet-noisy biological structures. The third sub-heading is quantum neurobiology. This topic has not yet gained wide acceptance and is still in its early stages. Its primary purpose is directed to understand whether the laws of quantum physics are effective in the biology of the nervous system or not. A further step in brain neurobiology, towards the understanding of consciousness formation, is the research of quantum laws' effects upon neural network functions. The fourth and final topic is quantum psychopathology. This topic takes its basis and its support from quantum neurobiology. It comes from the idea that if quantum physics is involved in the normal working of the brain, diseased conditions of the brain such as depression, anxiety, dementia, schizophrenia and hallucinations can be explained by quantum physical pathology. In this article, these topics will be reviewed in a general framework, and for the first time a general classification will be made for the quantum brain theory.

1. Introduction

More than a century ago, the beginnings of quantum physics brought two important points of discussion. The first was whether consciousness or a conscious observer had a role in determining the outcome of a quantum measurement. This argument got so heated that it was seen as a problem among quantum physicists and gained the name “the measurement problem”. Various solutions were suggested for this problem. Even the founding fathers of quantum physics became divided into various schools and factions on this point. This issue still remains unsolved among quantum physicists, and quantum measurement is still known as the “measurement problem” (Tarlacı, 2012c). Unending arguments still persist today about whether the person who in classical physics is merely the “observer” is in quantum physics an observer or a “participant” in the measurement, or even whether this person determines the outcome of the measurement. From the beginnings of quantum mechanics until today, answers have not yet been found to the place of the observer/experimenter in the Copenhagen interpretation (Cramer, 1986), or the concepts of many worlds or hidden variables or other suggested solutions. Theories on the effect of consciousness and the observer in quantum mechanics have been proposed by such eminent physicists as John von Neumann and Eugene Wigner (Wigner and Margenau, 1967), John A. Wheeler (Wheeler and Zurek, 1983), and Ewan H. Walker (Walker, 1977). However, objective theories have also been proposed which say that the observer has no relevance to the mechanism or result of a quantum experiment.

The second debate which started immediately after the birth of quantum physics was whether physics concerned only non-living materials or whether the laws or quantum physics operated in biological structures. However, this debate and field of thought did not approach the dimensions of the measurement problem. The most important

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http://dx.doi.org/10.1016/j.ijpsycho.2015.02.016
0167-8760/

factor restricting the debate was the perception of biological structures as "warm-wet-noisy", and the impossibility of the operation of quantum physics in such an environment (Tegmark, 2000). However, when we consider biological entities, all biological structures can be reduced to biochemistry, and at a deeper level to quantum physics, down to processes at the level of ions, small molecules and proteins (i.e. receptors, ion channels and enzymes). In particular there is no "cut-off point" demarcating the boundary between classical physics and quantum physics (Tarlacı, 2011). These days quantum photochemical reactions are seen as normal, but it is only in the last ten years that it has been understood that quantum mechanics forms the base of the senses of sight and smell, photosynthesis, and magnetic direction finding in animals. The emergence of new evidence from similar studies has recently mediated the birth of quantum biology, despite long resistance. However, today the opponents of the quantum biology are fewer and hundreds of papers on the subject can be found in the archives of physics.

From the viewpoint of cognitive neurology, we now well understand the nature of nerve cell activity: the creation of action potentials, ion exchange, the use of energy, axonal transport, the vesicle cycle, and the production, cycle and breakdown of neurotransmitters. What we do not understand is how experience is formed in our material brains, and how consciousness is born from unconscious materials. In particular, classical physics has nothing to say on how to understand internal experience (Tarlacı, 2010b; Blutner, 2010). As a result of this shortcoming, a new concept, quantum neurobiology, has come into existence. Quantum neurobiology is a concept to which we are not yet fully accustomed to: it refers to a narrow field of the operation of quantum physics in the nervous system such as the emergence of higher cognitive functions like consciousness, memory, internal experiences, and the processes of choice and decision-making which are products of the warm-wet-noisy brain. According to quantum neurobiology, quantum physics is involved in biological processes, and consciousness, memory, internal experiences, and the processes of choice and decision-making, which are the products of the warm-wet-noisy brain, may be the result of the operations of quantum physics. According to this, and in contrast to the classical view, the information processing units are not the nerve cells but smaller quantum physical processes inside the cells and forming connections between them. As will be seen, this is an example of deep reductionism, and can be thought of from another viewpoint as *super-reductionism*. Theories relating to quantum neurobiology have been proposed which are verifiable or falsifiable experimentally.

If quantum physics is involved in the neurobiological operation of the normal and healthily functioning brain, then it may be considered to have a role in the pathological processes of mental illnesses (Pylkkänen, 2010). This has now been given a name: quantum psychopathology (Globus, 2010; Mender, 2010). The idea of quantum psychopathology is that it will work in the same way in which quantum neurobiology successfully explains the conscious workings of the healthy brain (Woolf et al., 2010). So far, theoretical and experimentally testable papers have been published on depression (Cocchi et al., 2010; 2012; Rasenick, 2012), schizophrenia (Zizzi and Pregnolato, 2012a, 2012b, 2012c; Zizzi and Pregnolato, 2012a, 2012b, 2012c), anorexia nervosa (Marlow, in press) and Alzheimer's dementia (Georgiev, 2002, 2009), and the topic has attracted a great deal of interest and attention. The next step will be an approach which will provide treatment (Cocchi et al., 2010, 2012).

In the past 30 years, the concepts of the dynamics of the quantum brain, mind and consciousness and the quantum brain theory have increasingly come up both in scientific publications and at congresses (Tarlacı, 2010a; Başar, 2010). However, the terminology has been used somewhat loosely. For example, "quantum mind theory" has been used when discussing whether the mind is involved in the measurement problem. The same term is used for the theories that attempt to explain how consciousness is created in the brain through the use of quantum mechanical calculations. As a result, it is necessary when using the term "quantum brain theory" to shed light on the subject under discussion. These concepts have also been reflected in popular culture, and wherever you go you see the mysterious word "quantum", and everybody trying to make money out of the mystery of quantum physics (Tarlacı, 2012a). A serious consequence of this cultural drift is the fact that the prefix "quantum" has earned a bad image among that part of the academic community with an interest in physics.

In this overview article, the quantum measurement problem will be briefly discussed. This is a topic which journals of theoretical physics have discussed from a philosophical point of view since the birth of quantum physics, almost as much as they have discussed advanced mathematics. The subheadings of quantum neurobiological theories and quantum psychopathology will be discussed from a quantum biological standpoint. The working of the brain according to quantum monadology (Nakagomi, 2006; Harrison, 2006), which is a metaphorical theory of the quantum brain, and S-matrix or Feynman diagrams (Başar, 2009) will not be dealt with in this article. All these topics were unofficially described as quantum neurophysics, quantum brain dynamics, or more narrowly as quantum brain/mind/consciousness, until they gained an official status with the regular publication from 2003 to the present of the journal *NeuroQuantology*, which covers these topics (Tarlacı, 2003). Today, NeuroQuantology is not just the name of a journal but of a scientific discipline (Tarlacı, 2012b; 2014). Because of the publication of an increasing number of quantum brain theories, the need was felt for a review to explain the position of the theory. A general review of quantum brain theory will be done in this article on the basis of a new classification (Fig. 1). The topics in this overview article will be examined on the basis of this new classification. We hope that this classification will be a guide for future publications.

2. The quantum measurement problem and consciousness

Since this heading is outside the scope of a neuroscience journal, only a general view will be presented here. The quantum measurement problem, or to use a more technical expression the collapse of the wave function, appeared soon after the birth of quantum mechanics, and a clear solution to this problem has yet to be proposed. The topic was transferred to the macroscopic level by the thought experiment of Schrödinger's cat (Tarlacı, 2012c). In this imaginary experiment, a cat is totally isolated from the environment in a box together with a radioactive atom with a half-life of 10 min. If we examine the state of the atom at the end of 10 min, we will see one of the two possible results, namely that its nucleus has either split or not split. If the atomic nucleus splits the cat will die, and if it does not, the cat will live. According to quantum physics, until an experimenter opens the box and sees the cat inside it, the cat is simultaneously both alive and dead. Or in technical terms, the living and dead states are superimposed. The observation of the experimenter who opens the box removes the cat from this superimposed state, and reduces it to one of the states of living or dead. If you think this is strange when you consider your cat at home, well, this is how things work in the quantum world.

When Erwin Schrödinger described the paradox of the cat (the cat that was both alive and dead at the same time) through his thought experiment, in search of a solution to the quantum world, ended up confusing both the experimenter and the cat. And it cannot be said that the confusion has been cleared up yet. The solution of the Bohr-Heisenberg Copenhagen School (Cramer, 1986) and von Neumann–Wheeler–Wigner (Wigner and Margenau, 1967) involves the observer or consciousness. When there is a conscious observer, anything which is observed presents us with all of its superimposed content as a single one of all the possible and potential states. Wigner goes further and wants to include consciousness as a hidden variable in the equations of quantum mechanics. In Everett's many-worlds/minds proposal, there is a branching and dividing wave function. Reality separates here into infinite and different consciousness, which have no knowledge of

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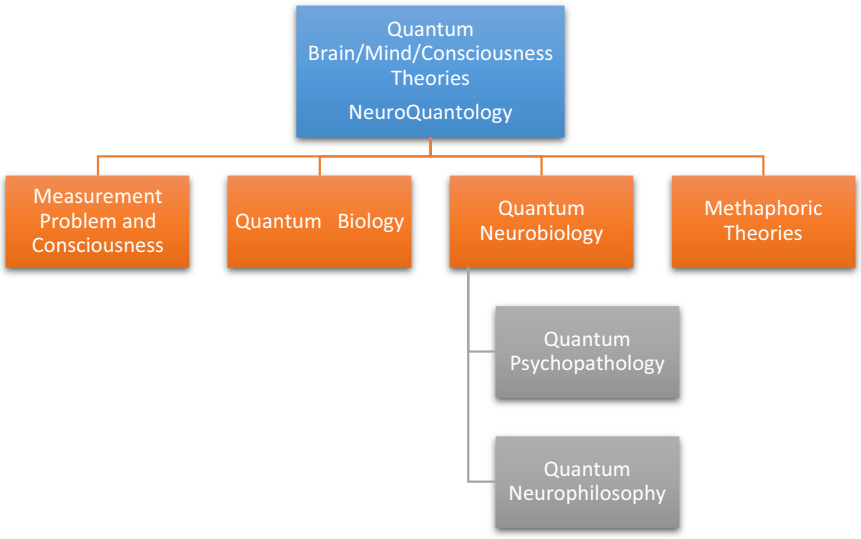

Fig. 1. A classification of the dynamics of quantum mind/consciousness/brain, quantum neurophysics and the quantum brain, or of the subheadings of research of the new branch of science of *NeuroQuantology*. There are three basic main topics and quantum psychopathology and quantum philosophy emerge as an essential result of quantum neurobiology. A further product of quantum neurobiology is quantum psychopathology. Metaphorical theories are a new viewpoint proposed to understand the functioning of the brain completely in the language of quantum mechanics (quantum monadology, s-matrix etc.), and its practice.

each other (Everett, 1957; Mensky, 2007). Decoherence, in the theory of objective collapse of Ghirardi et al. (1986) and Penrose (1989), presents solutions which are entirely independent of consciousness and an experimenter. In decoherence theory, the shift from quantum probability to the level of reality stems entirely from environmental effects. The process of probability which is measured is an open quantum system, and the way open systems behave determines their interaction with the environment. Therefore, there is no need for an observer in the measurement process. In Penrose's objective reduction theory, only one of the choices remains when measured or observed. Superimposition separates out one of the choices by quantum gravity at the level of Planck space–time. As a result, the laws of physics and nature keep to a set of rules when separating the two possibilities. There are other theories which use the same basic point of view and propose that consciousness directly affects the shift from probability to reality (Bohm, 1980; Stapp, 2001; Wigner and Margenau, 1967; d'Espagnat, 1999; Squires, 1994).

The basic question which is the reason for the appearance of all these different suggested solutions and schools is this: does an experimenter or an intentional/conscious observer affect a quantum process which involves probability? Or is a state of superimposition reduced objectively to a final state as a result of the laws of physics, independent of an observer? Put more briefly, this is the question: are we participants in the universe, or only observers? When looked at in this way, there is a very broad literature on the topic of possible mistakes in the basic principles including discussions of nearly a century of quantum ontic, epistemic and causal philosophy(Mehra and Rechenberg, 2001).

Today we have an idea about where the problem of the observer in measurement may have originated. At least, knowing these points allows us to get a step closer to the solution. All thoughts including science can be expressed in language. Science has a language which suits the times. The language of quantum mechanics has been inherited from classic Newtonian physics, which ruled for 400 years. This language was used for a world of macroscopic, deterministic experiences and calculations. This same language and patterns of thought have been seen to be inadequate when used to describe the strange properties of the quantum world. We have become accustomed to a new language with the theories of general and special relativity, but the principles of language are still not suited to describing subatomic structure and its behaviour. At its simplest, the principle of *tertium non datur* – the lack of a third possibility – does not apply to quantum mechanics. In general terms, there is as yet no suitable language and vocabulary for quantum mechanics. There have been attempts to create a new language (*rheomode*) with a subject–verb–object structure for the quantum world (Bohm, 1980; Stamenov, 2004), but it did not have the expected effect. An acceptable language cannot be created artificially. Language changes naturally with experiences and time. It cannot be expected that artificial changes will be applied in practice, and in any case according to Derrida, there is no universal language which can express all thoughts.

At the same time it is seen that when the experimental apparatus and the experimenter are regarded as a unified system, there is a problem with collecting and interpreting the information of that system. When expressing a quantum system with classical information, there is a loss of information. We, as the experimenter/observer, change the relationship between the autonomy and reliability of the information obtained from the system (von Lucadou, 1995), and this causes a loss of information (Weizsacker and Weizsacker, 1972). In addition, the measurement instruments and the characteristics of micro-universe particles which are carried to the macro universe such as position, velocity and momentum interact and are recorded. In this process information loss occurs and the level of loss is closely related to the descriptive language which science uses.

One of the crucial questions with quantum mechanics arises from the relationship of the experimenter and the experimental apparatus which has been set up. A direct answer to this question would have the power to basically change our understanding of the universe. In general terms it is accepting at what level measurement will be completed. It is after the result is learned by the observer, or after it has been recorded by the instruments? An easier but more striking statement is this: are we observers, or participants? The founders of quantum mechanics such as von Neumann (1955), Wigner and Margenau (1967) and Wheeler do not accept the separation of experimental instruments and conscious observer. A completely closed system without an observer is an internal system. When this internal system is divided into observing and observed parts, this means that we are describing it with external physics. In this condition, the world of the tools of the observer is defined as the external system. Quantum external physics is related to the ontological side of quantum theory, while internal physics is related to its epistemic side. Internal physics obeys universal laws and describes objective existence that is existence which is independent of humans and their observations, while external physics is related to perception, observation, measurement and evaluation.

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External physics seeks the existence of the measurement system of an experimenter or observer as a condition. However in internal physics, on the contrary, there is no such thing as a separation between the subject and object, and so internal physics is not concerned with measurement and evaluation but with existence. As will be seen, a comment on any measurement must be a mutually completing ontological–epistemological interpretation. In suggesting solutions to the quantum measurement problem, this basic starting point blurred each other (Koç, 1993).

Alongside all this theoretical discussion, there have been studies showing that a conscious observer or intention has an effect on quantum physical processes that involve probability (Radin et al., 2012; Schmidt, 1982; Ibison and Jeffers, 1998) and other random processes that involve probability (Schmidt, 1974; Jahn and Dunne, 2005; Dunne et al., 1988). There is even proof that the expectations of an observer can change the outcome of an experiment (Wiseman and Schlitz, 1999). Historically, the person who has worked most on this topic and who today even still uses the methodology and the apparatus in his laboratory is the physicist Helmut Schmidt. He has researched the effect of consciousness and the observer on quantum mechanical probability processes for many years, and reached the conclusion that under certain conditions consciousness interacts with random physical processes (Schmidt, 1970). More recently, similar results have been obtained in other laboratories (Jahn and Dunne, 2005; Dunne et al., 1988; Radin et al., 2012, 2013). However, the experimental findings have been disregarded by many of those working with quantum physics because they are at odds with the existing paradigms. According to the results of these studies, quantum objects are aware that they are being observed, and show a change in their behaviour according to intention. This statement is in deep conflict with our general understanding of the universe and our objective outlook. It can even make some quantum physicists jump out of their seats. But when we look at the history of science, we can see that there was the same resistance to any revolutionary idea. Over the past fifty years, approximately 800 studies have been published by 68 different laboratories on the effect of consciousness, intention and observation on random processes. For a significant proportion of these studies, the effect of the observer was significantly reflected in the statistics.

There are four recent studies investigating experimentally the effect of consciousness or intention or the observer on the quantum mechanics wave function. The first two of these were carried out at York and Princeton universities, and investigated whether ordinary people had an effect on the double slit experiment (Ibison and Jeffers, 1998). The third investigated the effect of people meditating (this word may cause discomfort to some solid-state physicists, but it should be thought of scientifically as meaning "those who have a greater ability to concentrate their attention") on the Michelson interferometer involved in the closed double slit system (Radin, 2008). The last study of recent times investigated the effect of meditators on interference in the double slit experiment (Radin et al., 2012, 2013). According to the results of York University, there was no statistically significant effect of ordinary people in the desired direction on HeNe laser interference with the effect of consciousness or intent; deflections in the desired direction were recorded. In the Princeton experiment, a medium statistically significant deflection was obtained in the predicted and desired direction. In the experiment which used a Michelson interferometer, a very significant effect was detected from the people meditating ($p = 9.4 \times 10^{-6}$), and the same effect was not observed from the control group. Finally, in Radin's study, participants sitting at a distance of 2 m were instructed to direct their attention towards or away from one arm of the interferometer. The experiment was performed under strict conditions and away from electromagnetic or other interference. The effects of heat, auditory feedback and meditation were investigated. The relationship to the global geomagnetic force (GMF-*ap* index) of concentrating on the interferometer and away from concentration from it and meditating or not meditating by the participants was analysed. According to this, a significant relationship was found between directing attention to the experimental apparatus, having previously meditated and a reduction in the magnetic field and a deflection of the interferometer in the desired direction. However, as with many other studies, it was not even discussed in the "solid physics" community. What can be understood is that we urgently need a paradigm shift in the way we understand and explain this new information (Başar, 2011).

3. Quantum biology

Quantum biology is defined as the application of the features of quantum physics[1] to biological objects and structures. At the base of quantum physics there are superposition, non-locality, entanglement and tunnel effect. Any research where these characteristics and the Planck constant are mentioned belongs to the realm of quantum physics. Apart from this, ionisation and the formation of chemical bonds, as well as biophysics, are reactions which at base are quantum physical. Erwin Schrödinger, one of the founders of quantum physics, wrote his book *What is Life*? in 1945. He was the first physicist to deal with quantum biology and its extension, the DNA structure. This book was forgotten for many years, but has recently become more popular and more referred to. In a historical overview of quantum biology, we should not forget the physicist Herbert Fröhlich. He proposed that coherence similar to the Bose–Einstein condensate, one of the basic features of quantum physics, could exist in biological systems and cells. He particularly upheld the idea that coherence could be the basis of biological oscillators (Fröhlich, 1968).

The most important characteristic of the brain is its holistic working and its state of coherence. It would seem difficult to explain this state of coherence and holistic working only by simple ion current and interconnected networks created by nerves cells. Looked at from the standpoint of classical science, our speed and fluidity of thought are much, much faster than the holistic working of the brain. In order to explain this holistic and coherent working, we need more than just the classical understanding. An ideal approach to explain this may be the Bose–Einstein condensate of quantum mechanics. It is argued that, although the Bose–Einstein condensate can be frequently demonstrated in non-living objects, a similar condition in biologically living things may be possible with the help of energy from the outside. Holistic working brought about in this way could be the source of consciousness, mind, memory, thought, personality, and the sense of self (Marshall, 1989; Kaivarainen, 2005).

All biological processes are at base biochemical, and at a deeper level the laws of quantum physics still come into play. Currently many "solid" physicists look at quantum physics with the eyes of "solid state physics" and this is still the dominant thought. But the rule is simple: any equation which includes the Planck constant is a quantum physics equation. Looked at this way, photochemical reactions, electron transfer and ion interaction, getting a suntan, photosynthesis, the sense of sight and the breakdown of DNA under ultraviolet light are all unquestionably quantum physical reactions. But even if these equations and the Planck constant appear in school books, it is not emphasised that these are "photochemical quantum equations". Most recently, with the advancement of research on photosynthesis, on magnetic direction finding in animals (*magnetoception*) and on the sense of smell, quantum biology has become an accepted subject.

Many studies have shown that the quantum physical phenomenon of tunnelling takes place in biological structures (Wan et al., 1999). In protein functions, it has been established that electron or proton transfer regularly takes place between some amino acids. For example, the enzyme ribonucleotide reductase-I makes an electron or proton transfer

[1] The terms "quantum mechanics" and "quantum physics" should not be confused in the reader's mind. Quantum mechanics is used is more used to refer to the mathematical basis, postulates and theories, whereas quantum physics is a broader umbrella which covers popular, experimental and observable processes.

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from a distance of 3.5 nm from the amino acid tyrosine to cysteine (Kelley and Barton, 1999). It has been shown that there may be electron transfer from the amino acid tryptophan to DNA (Rajski et al., 1999). Among the most typical electron carriers in living things are cytochromes. Cytochromes are formed from a molecule core known as a heme. At the centre of the heme is an iron ion which pass from the second degree of oxidation to the third, and this ion makes electron transfers (Miyashita et al., 2005). This structure is part of a structure known as the respiratory chain. It should be recalled here that the respiratory chain is known as an electron transport system. Quantum physics can show itself in biological structures in the shape of superposition, entanglement, quantum information processing and matter–wave interaction, and there is much experimental proof on this topic (Arndt et al., 2009)

3.1. Ion channels

The characteristics of quantum mechanics such as quantum bits, non-locality and entanglement, tunnelling, interaction between particles, Bose–Einstein condensate, waves being particles and fields can open new horizons for us in our understanding of the brain. A quantum bit (*qubit*), unlike the classical bit which is either 1 or 0, provides many more choices. According to classical knowledge, ions like calcium or potassium pass preferentially through their own ion canals, and each ion passes through one ion canal. Ion canals are around 1.2 nm in size and the interior of the canal is around 0.3 nm. However, when we look at it from the viewpoint of quantum physics, one ion does not have its effect only by passing through one ion canal. Rather than one ion passing through a single ion canal, it also has an effect on the neighbouring canals. For example, according to the quantum uncertainty principle, the uncertainty of a calcium ion is 0.04 cm, or four thousandths of a centimetre. According to this value, the area over which this uncertainty is effective is 100 million times the diameter of the ion itself. When we consider that ion canals are between 2000 and 12 000 μm^2, and there are a billion calcium canals in the brain, the uncertainty arising from this effect will be unbelievable. The same is true for potassium ions. A potassium ion has a De-Broglie wavelength of 0.05 nm and it has been calculated that it can perform quantum tunnelling and diffraction through an ion canal 0.25 nm wide. As a result, all ions are in a mutual relationship with each other over a short distance and independent of distance. The same is true not only of ions, but also of neurotransmitters. One neurotransmitter, as well as linking with a single receptor, in fact also affects the other receptors in its near neighbourhood. For example, a neurotransmitter 8 nm in diameter affects an area of 63 nm. The effect is not just that of a key going into a lock and opening the door. What quantum physics tells us is that a key goes into a lock but that it also plays a part in opening other doors. Neurotransmitters at synapses and ions are probably under the influence of quantum entanglement (Bernroider and Roy, 2005).

Another aspect is that in quantum physics each particle is not independent from the others. It is influenced by effect at a distance and interaction with other particles. It interacts with other ions in the environment, water molecules and canal proteins. A change in the state of one particle immediately changes the state of another. For example, a change in one particle in a system of n particles immediately changes the states of 2^n particles with which it is in a relationship. This may seem like voodoo magic. There is no connection between them and the interaction is independent of distance (Marshall, 1989).

3.2. Vision

The best example of photochemical process in living things is vision. Sight begins in the retina, which covers the back of the eye. The retina is a layered structure composed of the nerve retina and the pigment epithelium. The nerve retina senses light by means of the photoreceptors which perceive light. The photoreceptors convert the energy of photons into bioelectrical energy. This congregation of retinal cells is where the information from light undergoes its first processing. There are two groups of photoreceptors — rods and cones. These generally resemble each other and convert the photons into electrical signals by means of chemical changes on their exterior surfaces. The structure of chemical substances found in the retina is changed under the effect of photons (isomerisation). This change sets off a chain of metabolic events in the cell which converts the energy of the photon into bioelectricity, and this reaches the brain to give the sense of sight (Stryer, 1996).

The rods are cells composed of proteins, lipids carbohydrates and water. Their interiors are full of rhodopsin and their cylindrical structure contains stacks of membranous discs. Their width is 6.0–6.5 nm. They enable vision in light ranging from dim starlight at night (10^{-2} photons μm^{-2} s^{-1}) to bright sunlight by day (10^8 photons μm^{-2} s^{-1}). When the photons of light strike rhodopsin, they excite an enzyme called phosphodiesterase along with a G-protein called transducin. Phosphodiesterase lowers the level of cyclic adenosine guanosine monophosphate (cGMP). In the dark, the level of cGMP increases. This enables a constant flow from the sodium ion (Na^+) channels of the outer parts of the rod, and creates a high resting potential. When the cGMP level falls or when it raises calcium ion (Ca^{++}) levels, Na^+ channels close. During the course of this opening and closing, the changes in ions give rise to an electric current. When rhodopsin is excited by a photon, it prevents the entry into the cell of 10^5 cations (positively charged ions) with each isomerisation. Electrical currents are transmitted to the brain by the nerve cells (Baylor, 1996; Stryer, 1996).

Cones enable colour vision and have greater spatio-temporal resolution. The wave of light which excites these cones at the highest level is different for the three types of cones. In each type, 11-cis-retinal is found. After light is absorbed, the change from 11-*cis*-retinal to 11-*trans* retinal takes 200 fs, and is one of the fastest photochemical reactions known. In bright light, a recovery time of 2–5 s is needed for this biological mechanism to change back again.

3.2.1. Can a single photon/quantum be perceived?

The displacement of an electron from any orbital by an atom or a molecule when it absorbs a photon's energy is a photoelectric effect. In fact there is no difference at all between a photon hitting the retina and a quantum mechanical photoelectric effect. The event at this stage is amplified and reaches the macroscopic level. Even without excitation by any photons, chemical changes happen because of heat in the human eye, and the response is perceived as if it was photon excitation. Background noise in the dark can be thought of as interference caused by the environment and fluctuations in the system in a resting state without any stimulus. In particular, 11-cis-retinal isomerisation, related to heat, and not to photons, has been observed. The rods enable seeing in the dark, and it has been shown that someone whose eyes are dark-adapted can detect 5–7 photons (Hecht et al., 1942). Some researchers have claimed that the vision threshold in humans is 2 photons (van der Velden, 1946). Some studies have claimed that the brain can distinguish 1, 2 and 3 photons (Sakitt, 1972). A response to a single photon has been observed under certain conditions from a single rod taken from the eye of a salamander and maintained in an artificial environment (Rieke, 1998). The response of a cone to a single photon is 10–100 times weaker and shorter in duration than that of a rod. It has been observed that the entry of 10^7 cations is prevented by the effect of a single photon on a single rod (Menon et al., 2001).

3.2.2. The unconscious collapse of the wave function in the retina

Does quantum collapse occur only in the presence of human beings? Does it happen before measurement information reaches the retina, or after? When light rays, or quantum mechanical photons of light, come to the retina (the eye), what happens? The photon is absorbed by the bonds between the 11th and 12th atoms after which an electron from the highest orbital is excited and changes from the π state to the π* state. The excitation of the electron (π*) enables the carbon to move

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freely between C_{11} and C_{12} in this bond. This structural change is known as the change from *cis* to *trans* and the process takes 200 fs. With this change, the opsin molecule separates and causes a series of changes. The Na^+ channels in the membranes of the rod cell close. Before this the flow of Na^+ was happening freely, so that the interior of the rod cell had a lower potential. With the closing of the Na^+ channels, a large potential change occurs (the inside of the cell becomes more negative, while the outside becomes more positive). This potential difference becomes an electric current. In this way, when a photon excites a rhodopsin molecule, 10^6 Na^+ ions of charge cannot enter the rod cell, and 1 pA of electric current is created for about 200 ms. This is equivalent to 2×10^{-13} and 1.6×10^{-19} Coloumbs of charge for each Na^+ ion (Wald, 1968; Rieke, 1998). This means that the information is on average flowing from the microscopic level to the macroscopic or mesoscopic level. After this, 2–3 action potentials are created in the optic nerve so that, progressively strengthened, it is brought into the macroscopic or classical world. This may mean that the collapse of the wave function can occur without the presence of a conscious human being or in other words that photons do collapse within the retina and subsequent processing of information at the level of neural membranes proceeds (Georgiev, 2011).

3.3. Photosynthesis

Light energy from the sun absorbed by plants enables carbon reduction. Photosynthesis, using organic molecules, is their way of obtaining nutrition with the help of light. Plants capture light using the natural green pigment chlorophyll. There are two different systems of photosynthesis in plants. Photosynthesis generally uses light of wavelengths from 680 to 700 nm. Chlorophyll is found in all parts of a plant, but especially in the leaves. The reaction, simply expressed, is like this. Photosynthesis starts with the ionisation by light of a chlorophyll molecule. The ionising energy gains amount ΔE of energy according to the basic quantum mechanical equation $\Delta E = hc/\lambda$. In ionisation, two electrons are released and are carried by what is known as the electron transport chain. These electrons are used in phosphorylation, and ATP (adenosine triphosphate), used as the source of energy in cells, is formed. The resulting sugar can be used as cellulose or as a source of energy.

Photochemical reactions occur not only in the leaves of plants but also sometimes in certain bacteria (Panitchayangkoona et al., 2010). Arriving photons convert carbon dioxide to sugar not individually but collectively in the centres of chlorophyll and with the maximum effect of coherence. They excite the electrons which act like an antenna (excitons) and are passed from one to another until they reach the reaction centre. At each step, a stronger coherent stimulus is formed. It has been shown that quantum coherence in electron transfer in photosynthesis lasts for a long time (600 fs) in the pigment–protein complex (Engel et al., 2007; Ishizaki et al., 2010). It is not known how this coherence is brought about in living tissue and under normal light conditions, but it has been shown that environmental noise rather than breakdown increases energy efficiency (Panitchayangkoona et al., 2010; Collini et al., 2010).

3.4. The sense of smell

In 1990, the biophysicist Luca Turin made a new proposal about how smells affect the receptors. However at the time this idea and theory were given little attention. At that time, he was working on the structure and smells of a large number of perfumes and investigating the relationships between them. Finally, he published an article which went outside classical science. In this article he proposed that smell receptors react not only to the shapes of smell molecules but also to their vibrations or phonons. Going further, he proposed that the way of turning molecular vibrations into a smell signal might be “inelastic electron tunneling spectroscopy (IETS)” (Turin, 1996). Classical knowledge held that the smell of each perfume had its own individual shape and that its own particular smell came from that structural difference in the same way as molecular weight, functional groups, polarity, acidity, basicity, and steric interactions. IETS is tunneling in smell receptors which are biological structures by taking an electron from an electron donor molecule (Franco et al., 2011).

Olfactory receptors are G protein-coupled receptors belonging to a multigene family consisting of over 900 genes in humans. G-proteins convert a stimulus into an electrical signal, after which the electric current reaches the olfactory centres of the brain. A G-protein stimulated by smell molecules sequentially stimulates other pathways and causes stimulation in a chain of steps. Smell receptors are like biological spectroscopes and start the sensation of smell by identifying activities at the sub-atomic level. According to Turin (1996), an electron is taken for electron tunneling from a different molecule. When the tunneling electron reaches the binding site it stimulates the receptors and the smell causes vibration. The pattern of vibrations is different for each smell, and is identified by the smell receptors. Even very small differences in the smell molecules result in very different vibrations and therefore different smells. Where then is the proof that electron tunneling is involved in the stimulation of olfactory receptors? The first is that many smells do not enter into the reduction–oxidation reaction (or electron exchange), and therefore the receptors have to take the electron they need for tunneling from another source. This can be a decaying electron carrier or an enzyme. At the same time, many electron transfers in enzymes need metal ions. Metal ions may be needed for the sense of smell. DNA analysis has shown that olfactory receptors are closely associated with zinc binding sites. It has long been known that zinc is a metal ion involved in the sense of smell and that a deficiency of it brings about a loss of the sense of smell; but its function has so far not been clear. Zinc can be seen as performing the function of a bridge in providing the necessary electron for tunneling (Turin, 1996; Brookes et al., 2007). Turin's theory of smell explained how a limited number of smell detectors could distinguish a larger number of different smells or perfumes. In addition, the theory explained why molecules with a similar structure had a different smell.

4. Quantum magnetoception

Magnetoception or magnetoreception refers to the ability of living things to sense direction, height and their position by the use of a magnetic field. It was first shown in 1966 in a study of European Robins that on the evidence of behaviour certain animals use the Earth's magnetic field to move over long or short distances (Wiltschko and Merkel, 1966). Later, this kind of ability was demonstrated in 17 other species (Wiltschko and Wiltschko, 1995). It was shown that a wide range of animals from bacteria to birds and from sharks to pigs make use of a magnetic sense (Kalmijn, 1971). This sense has been called the sixth sense.

The Earth's magnetic field resembles the dipole field of a giant bar magnet. The lines of the magnetic field start from the south and enter the planet from the north. At the magnetic equator, the lines of the magnetic field are parallel to the surface of the Earth. The magnetic field is strongest at the poles and weak at the Equator: 31 μT (3.1×10^{-5} T) at the Equator, 20 μT (2×10^{-5} T) at 50° of latitude, and 0.1–10 nT (10^{-10} to 10^{-8} T) in outer space. At various points on the Earth's crust, a concentration of ferromagnetic minerals causes local variations in the magnetic field; these variations are small, below 1%. There is a magnetic field wherever there is an electric current or ion exchange, not only in the planet, but also in the heart (10^{-10} T) and the brain (10^{-15} T or 0.1 pT).

In the world of animals, the Earth's magnetic field is used to sense direction in two different ways. In the first, the lines of the magnetic field are used and these help movement in a north–south direction. These magnetic lines are used by invertebrates such as molluscs, flies and crustaceans, as well as by vertebrates. For example, young *Green Turtles* migrate over a long distance (Lohmann et al., 2004), from

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the coast of Melbourne in Australia to the coast of Florida in the USA. It has been shown that these turtles sense magnetic direction with an internal magnetic field sensor. These migrations occur despite many natural obstacles such as the waves of the sea, but they still reach their destination. The second method involves direction finding by means of the angle and intensity of the magnetic field (Lohmann et al., 1999). Some birds, sea turtles, salamanders and lobsters can distinguish very small variations in the intensity of the magnetic field (Fischer et al., 2001).

4.1. Magnetic receptors in living things

It has been shown that the magnetic mineral crystals magnetite (Fe_3O_4) and greigite (Fe_3S_2) are found in certain animals. It has been established that these crystals are formed within the dendritic extensions of nerve cells in honey bees, salmon, sea turtles and birds (Johnsen and Lohmann, 2005; Falkenberg et al., 2010). The crystal are about 50 nm in diameter, and in the absence of a magnetic field show a magnetic characteristic of ($B = 0$). If there is an external magnetic field, they turn freely. In addition, there are also superparamagnetic crystals in living things, and these have no magnetic field of their own. However, they are affected by being exposed to a magnetic field. In pigs, superparamagnetics have been found embedded in nerve cell membranes (Davila et al., 2003), and it has been shown that they accumulate along the cell membrane in synaptic areas (Fleissner et al., 2003; Gauger et al., 2011).

In birds, magnetite in the form of iron-3 (Fe^{3+}) has been found in the upper mandible of the beak (Winklhofer et al., 2001). At the same time, magnetite has been found in fish in that part of the anatomy which is similar to the upper part of a bird's beak (Diebel et al., 2000). Sensation in this area is handled by the ophthalmic section of the trigeminal nerve (Walker et al., 1997). Recordings made from this nerve showed a response with even a 0.5% change in the Earth's magnetic field (Semm and Beason, 1990). In studies in the nerve cells of molluscs, it was shown that they could respond to magnetic fields with a change in the electric current in their nerve cells (Lohmann et al., 1991).

In birds, the most important substance for magnetic direction finding is cryptochrome, found in the retina of the eye (Solov'yov et al., 2007; Ritz et al., 2000). Cryptochrome-2 has been found in the human retina, but it is not known whether it performs magnetoception. This substance is sensitive to stimulation by blue light and at the same time is sensitive to magnetic fields. Cryptochrome is 7 nm in size and is found in the rods of the retina. A magnetic field affects the base exchange between tryptophan and flavin adenine dinucleotide (FADH) joined by a proton in cryptochrome. There are unpaired electrons on free radicals. Unpaired electrons have internal angular momentums or spins. While an electron which is close to the nucleus of an atom is affected by the nucleus, the spin of an unpaired electron which is far from the nucleus is sensitive to the magnetic field of the environment. The magnetic effect changes the spin from a singlet state ($s = 0 \rightarrow 2\,s + 1 = 1$) to a triplet state ($s = 1 \rightarrow 2\,s + 1 = 3$). In darkness, the transfer of electrons back from tryptophan to FADH changes cryptochrome into an inactive state. These changes take place in as little as 10–300 ns. New studies have shown that magnetic lines can be seen with a quantum cryptochrome compass working in a magnetic field. At the same time, it has been shown in experimental models that in “warm and wet” birds, quantum entanglement and coherence may be involved in magnetic direction finding (Ritz et al., 2000).

When a charged particle is exposed to a magnetic field, it is exposed to a force which is related to the movement and direction of the field. This is the Lorenz force, and its strength is related to the size of the magnetic field, the charge and speed of the particle, and the angle between the field lines and the movement. Therefore, if an electrically conducting bar moves in a direction which is not parallel to a magnetic field, positively and negatively charged particles congregate at opposite ends of the bar. This causes a stable voltage and is known as electromagnetic induction. It is possible that sharks' perception of the Earth's magnetic field works in this way. In sharks, the ampullae of Lorenzini, which are an organ filled with a liquid the consistency of jelly, are the equivalent of the bar of the magnet (Kalmijn, 1971). In an experiment supporting this, a magnet attached to the nose of the fish disrupted direction finding, while a normal metal bar did not have the same effect (Kirschvink et al., 2001).

In pigs, the basal optic root takes extensions from the ganglion cells in the eyes, and shows a clear response to changes in a magnetic field (Semm et al., 1984). However, the amplitude of the response is also related to the wavelength of light entering the eye. This response to a magnetic field is removed when the optic nerves are cut (Semm and Demaine, 1986). Many studies have established a link between the pineal gland and a magnetic sense (Deutschlander et al., 1999). It has been shown that recordings made from the pineal glands of pigs can show responses to changes in the magnetic field. It has been shown that pigs can distinguish very small magnetic variations of 186 μT (1.86 Gauss). When other pathways to the gland are cut, the response of the pineal gland to magnetic field changes is reduced, but does not disappear entirely. Therefore, it is suggested that the magnetic sense comes directly from the gland itself (Demaine and Semm, 1985; Johnsen and Lohmann, 2005).

4.2. Magnetic field and consciousness in the human brain

The brain has its own very weak magnetic field (10^{-15} nT or 0.1 pT). This field comes from the firing of nerve cells, and the movement of ions into and out of the cells. There is in any case an electrical field on every nerve cell axon in the brain, arising from ion flow. Wherever there is an electric current, there is also a magnetic field perpendicular to it. Because the nerve cells in the brain are distributed randomly, the total of the magnetic field which they create is zero. However, the arrangement of nerve cells in the neocortex and the hippocampus in parallel layers increases local magnetic fields. In the human brain cortex there are 10^4 nerve cells per mm^2. In this volume there are about 200 neighbouring nerve cells. The firing of one cell is enough to affect many nerve cells. As electrical fields combine with each other, the magnetic fields arising from them are superimposed on each other. This superimposition not only makes the brain's magnetic field clearer, but at the same time creates a coherent relationship between distant areas of the brain.

Coherence starts in a local area with coherent firing, and spreads to the whole brain (Bullock et al., 1995). It has been shown that synchronous firing at certain frequencies is related to the state of consciousness and attention, and that gamma wave oscillation at 40–80 Hz is related to attention and perception. It has been suggested that the magnetic field in the brain contributes to synchrony, or is the cause of it. Therefore, as synchronous firing accompanies consciousness, attention has been focussed on the relationship between the magnetic field in the brain and consciousness (Singer, 1998; McFadden, 2002, 2007; Cherry, 2003). However, there has been serious criticism of this theory (Pockett, 2002, 2007).

The brain's magnetic field may be an epiphenomenon of consciousness, that is, a phenomenon reflecting underlying dynamics. Or just the opposite, the brain's magnetic field may have a regulating effect on consciousness or may even be the source of it. In our daily lives, we can decode the very complex magnetic information in radio and television and transform it into sound and vision. Similarly, the nerve information in the brain may be represented electromagnetically. Coherent firing in nerve cells may provide the possibility for information to pass from the nerve cells to the magnetic field (McFadden, 2002, 2007).

5. Quantum neurobiology

Many physicists have published on the quantum measurement problem and its relation to the observer or consciousness, and it is

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generally physicists who understand deep mathematical formulae. However, quantum neurobiology is a field which neurologists can conceptualise more easily. This is because it is based on an understanding of the extent to which quantum physics contributes to the higher consciousness functions of the brain such as the place of memory storage and recall in the biology of the brain, free will, decision making, consciousness and different states of consciousness, and how anaesthesia temporarily suspends consciousness. The laws of classical Newtonian physics, key-lock models, taking the functions of nerve cells or synapses one by one and non-linear approaches are insufficient to explain how higher conscious processes arise in the material brain (Tarlacı, 2010b). Even though many biologically based theories have been put forward, some are too metaphoric. Generally, since the basic functioning units in these theories are nerve cells or at the smaller quantum scale (such as microtubules or spins), some think of these theories as "super reductionism". What is interesting is that this quantum biological super reductionism results in the working of a holistic brain.

The topic is one of the most discussed in academic circles and in popular culture. Some solid physicists say it is impossible, but others regard it more warmly as possible. One of the most serious arguments against the functioning of quantum physics in the neurobiology of the brain is that it is "warm, wet and noisy" (Tegmark, 2000). However, we know that seeing, photosynthesis, the sense of smell and magnetoception are examples of quantum biological phenomena, which under certain conditions can operate in accordance with quantum physics in warm and wet living things, including the brain.

5.1. Quantum tunnelling in synapses

It was proposed by two different physicists and one neurologist that synaptic transmission occurs not according to the classical diffusion model and the key lock model but by quantum tunnelling. Since many neurologists do not know quantum physics, it is understandable that these kinds of theory should first have been proposed by physicists. Tunnelling is a phenomenon specific to quantum physics. In tunnelling, a quantum particle which does not have enough energy to pass a barrier nevertheless has the possibility to do so. What defines that possibility is the width and height of the barrier. The particle does not jump over the barrier but gets to the other side as if it had tunnelled through it. One of the theories was proposed by the physicist Ewan H. Walker (1977, 1991), and the other by Nobel Prize winning neurologist John Eccles and physicist Friedrich Beck (Eccles, 1990; Beck and Eccles, 1992; Beck, 2008). These theories propose it as a new approach not only to the workings of the brain but also to the creation of consciousness, and the question of the consciousness–brain connection.

Neurotransmitters cycle in the form of small packages (quanta) and each quantum forms a synaptic potential of a certain size. Synaptic potentials are formed as miniature end plate potentials (MEEP) either of their own accord or by an incoming stimulus. As well as chemical synapses there are also electrical synapses. Synaptic gaps of 120 Å in electrical synapses and 150 Å in chemical synapses are suitable for quantum tunnelling. According to Walker's theory, quantum tunnelling occurring in chemical and electrical synapses is the origin of the formation of consciousness. In the synaptic gap, electrons, ions and neurotransmitters perform tunnelling. Microtubules and RNA within the cell as a source of tunnelling electrons are added to the theory as electron donors. Walker notes the match of his theory with the link between the conscious state of the brain and the 40 Hz gamma frequency, reached by electron tunnelling calculation. He also proposes that MEEP potentials occur as a result of spontaneous quantum tunnelling of thermal origin (Walker, 1977, 1991).

Quantum tunnelling is also at the base of the theory of Eccles and Beck (Eccles, 1990; Beck and Eccles, 1992; Beck, 2008). In their theory, they link the fine structure of the neocortex with quantum physics. They see the basic unit of the neocortex as the dendrons. Dendrons are the basic units of the material brain. In contrast to this, Eccles places psychons as the basic units of the mind. That is, for each biological dendron there is a mental psychon. Psychons are a final evolutionary development of the neocortex. According to Eccles, no mammalian brain cortex can reach a state of consciousness without Dendron–psychon interaction. Mental intentions arise from the psychons, and dendrons in relevant areas of the brain affect them. The thousands of stimuli in the dendrons result by post-synaptic potentials (EPSP) in visible bodily movements (raising the arm, speaking) and invisible results (*thinking, imagining*). All interactions between psychons and dendrons take place in the context of the laws of quantum physics. Synaptic chemical cycles function entirely by quantum probability and tunnelling. All of these coherent interactions in the brain form the unity of our sensations, internal world and consciousness. This explains how mental intentions cause regional blood changes in the brain. That is, it presents a solution to the problem of the connection between mind and brain.

5.2. Spin mediated consciousness theory

According to spin-mediated consciousness theory (Hu and Wu, 2004, 2008), quantum spins are the meeting point between mind, consciousness and the brain. These spins can be called mind pixels, and are found in the nerve cell membranes. All spins or pixels form a spin network with quantum entanglement. Even though entanglement objects are spatially separate from one another, they seem to be in communication in a way which is peculiar to quantum physics. All pixels have an effect together by means of entanglement, and the unity of consciousness is brought about. Spin, like mass and charge, is an intrinsic characteristic of the particle. A rough comparison is to the spin of the Earth as it rotates.

According to this theory, the appearance of consciousness in the brain is reduced to the interaction of the spins of atoms in the cell membranes. The action potentials arising from ion exchange in nerve cells is arranged through the spin interaction of atomic nuclei, paramagnetic oxygen (O_2) and nitric oxode (NO). The spins of the nuclei of some atoms in the cell membrane proteins form quantum entanglement to different degrees. Spins in a state of entanglement form quantum spin nets, just like nerve cell nets. These nets affect nerve cell nets and at the final stage the macroscopic brain. With this effect, conscious processes and consciousness are brought about (Hu and Wu, 2004, 2008).

The spin mediated consciousness theory is also a theory which takes magnetic fields into account. Fluctuations in the internal magnetic field continually give rise to changes in the spin net in the entanglement state of the brain. The severity of these changes is related to the density of O_2 and NO in the brain and inside the cells. Thus, the changes are under the control not only of the spins in nerve cells, but also of non-linear dynamics such as nerve cell coherent firing in the brain. Atoms which have nuclei with spins such as ^{1}H, ^{13}C and ^{31}P cause changes in the magnetic field because of paramagnetic effects. At the same time, a magnetic field is formed by the magnetic dipoles of unpaired electrons in the nuclei of O_2, NO and ^{1}H. All of this mutual interaction and fluctuation brings about the state of consciousness and mind (Hu and Wu, 2004, 2008).

5.3. Objective reduction in microtubules

This theory is currently the most commented and can be tested by experimental methods. It is suggested that the basic operational units bringing about consciousness are not neurons but the microtubules which are found in nerve cells and which form their cytoskeleton. Microtubules (MTs) are a particular form of nanometric tubules (around 25 nm in diameter and full of water) formed from dimer proteins known as tubulins. The tubulin proteins aggregate into 13 units/cycle to form cylindrical polymers constituting the walls of the MTs. Tubulin are dimers of 4–5 nm diameter, among the two structural forms, alpha and beta are located the basic unit of quantum bit calculation (Hameroff and Penrose, 2014). Tubulins are dipoles, this means that

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they can give rise to coherent structures able to manifest quantum phenomena of superposition and entanglement. The MT lengths are very variable and they can be as long as an axon (Desai and Mitchison, 1997). They not only form the cytoskeleton of the cell but also have a function in cell communication.

Each neuron has about 10^7 tubulins, and transitions occur within nanoseconds. This makes 10^{16} operations for each neuron. According to the classical approach, the brain has 10^{11} neurons as the basic units of operation, but this number rises to 10^{27} when MTs enter the picture. According to the theory, MTs are also the quantum physical location where consciousness arises. The collapse of the quantum wave function happens in an objective way in the tubulins. *Objective reduction* (OR) happens without the need for a conscious observer. This OR operates totally under the laws of gravity in the dimension of Planck space–time. Tubulins behave in this situation as qubits, the operational unit of quantum information. That is, they can be found in alpha and beta states, and even in an alpha–beta superimposed state. The macroscopic brain state and consciousness arise as a result of successive and continuous qubit calculations. The proteins which accompany the microtubules in the cell (MAP) manage OR with a kind of fine tuning (orchestrated, Orch OR). That is, quantum Orch OR means consciousness, and in one way consciousness means OR. Consciousness comes from successive and continuous quantum Orch OR. In this way we feel a continuity and flow in our consciousness (Hameroff, 2001, 2006, 2007; Hameroff and Penrose, 2003, 2014).

The Orch OR theory of consciousness and higher states of consciousness (Hameroff, 2001, 2007; Hameroff and Penrose, 2003, 2014) may explain free will and choice, the effect of anaesthesia (Hameroff, 1998, 2006), the possible connection between the sol–gel change in cells and the effect of gap junctions and the coherent 40 Hz oscillation, and the solitonic effect of the local magnetic field (Hameroff and Penrose, 2003, 2014). It has been suggested that consciousness is not local and limited to the brain and the inside of the skull, but has extensions which are universal in meaning. At the same time, a relationship has been established between psychopathological diseases and the MT theory of consciousness (Georgiev, 2002; Woolf et al., 2010). There has been opposition to the theory and objections have been made that it could not operate in a "warm-wet and noisy" brain (Tegmark, 2000). Famous physicists such as Hawking, in particular, argue that neither this theory nor physics has much to say about consciousness (Penrose et al., 1997).

5.4. Quantum brain dynamics

It was Hiroomi Umezawa who proposed that quantum field theory (QFT) might have a role in the working of the brain (Riccicardi and Umezawa, 1947; Stuart et al., 1978). More recently, the theory has been developed by Jibu-Yasue, and Karl Pribram (1966) has stated that it might be related to the holographic brain model. More recent new models have added dipole wave quanta, the "dissipative brain" (Vitiello, 2003), and the concept of dark energy (Capolupo et al., 2013). In this theory, the brain is considered as a multiple system composed of lower levels. With the creation and annihilation dynamics in this system, a collective behaviour occurs. The final product of this system is memory.

In addition to nerve cell nets, dendritic nets have an important place in this theory. Dendrites have spines in three places. Electrical synapses and most chemical synapses are found on this region of the dendrites. These connection areas are sensitive to neurotransmitters, ions and electrical current. In this way, an electric current arising along the threadlike structure of the protein molecules in the cell skeleton in the manner of a superconductor is a special solitary wave. This wave is called a soliton. Solitons come from nonlinear effects above the background. They can interact with other solitons, and can travel over very long distances without a loss of energy. Coherent solitary waves carry energy without loss, and are called Davydov solitons or dipolar solitons (Davydov, 1979).

The basic operational unit in this theory is the corticon. According to the theory, the basic structure of the brain is formed not of neurons but of corticons. The corticon system can be represented by a corticon field. Corticons can be found both inside and outside nerve cells, and include glial cells. They are not limited to nerve cells alone. The creation and annihilation dynamics occurring in the corticons by boson exchange gives rise to memory and consciousness. The structure of corticons spreads to the whole cell net of the cortex (Vitiello, 2003). Water molecules create regions of vacuum about 50 μ in diameter. Thus the water in the brain is separated into many regions each with a volume of 50 μ. In these regions, the electric dipole moment vectors of the water molecules are coherent, and all have vectors in the same direction. Each water molecule is swimming in the same direction, like a synchronised swimming team. Each region of vacuum is in a non-local relationship with the other regions of vacuum. This behaves in the brain like one huge system, spreading in waves from one vacuum to another. In these interrelated vacuums, a macroscopic organisation occurs. Memory may thus be a vacuum state. The change from one vacuum state to another is called vacuum phase change. Learning or memory in a system like the brain is the creation of new vacuum states with entering energy (Riccicardi and Umezawa, 1947; Stuart et al., 1978; Jibu and Yasue, 1995; Globus et al., 2004).

Memory recall, that is, remembering, is related to the Nambu–Goldstone Boson (NGB), while memory problems or forgetting are related to instantons. The NGB is a boson with near-zero mass and very little energy. Spontaneous symmetry breaking in vacuums is re-created by the creation of an NGB. NGBs behave more like waves than particles, and provide long-range correlation in the brain. In this way, individuality is lost in the whole. The instanton is another theoretical quantum particle which comes into play when remembering or recalling to memory. If internal or external energy comes to a nerve cell or to the dendritic net, the existing consciousness state in the person changes to a new state of consciousness. Memory changes to a different state with a vacuum phase change, and a new memory is created. The new vacuum state is the total of the previously existing memory and the memory change caused the stimulus of the entering energy (Jibu and Yasue, 1995; Globus et al., 2004).

Spin mediated consciousness theory, quantum brain dynamics and the Orch OR theory may bring an explanation to the mechanisms of the consciousness–brain connection problem, free will, the unity of consciousness, qualia, non-algorithmic information processing, remembering and forgetting over time, and the effect of anaesthesia. All of this is an experimentally testable theory.

5.5. Connected and entangled brains

Quantum entanglement is a state where objects are separate from each other but nevertheless in communication. There is no such thing in classical physics. Entanglement was demonstrated best in the Einstein–Podolsky–Rosen (EPR) experiment, which is named after Albert Einstein, Boris Podolsky and Nathan Rosen. In their article "Can quantum mechanical description of physical reality be considered compete?" (1935), they reached the conclusion that the ψ (psi) function, which expresses the collapse of the wave function of microuniversal objects in quantum mechanics, was not a complete description. Einstein did not accept a means of communication travelling faster than light, and maintained that quantum theory was not complete. It was for this reason that he called it "spooky action at a distance". Later John Bell (1964) prepared the theoretical ground, and Alain Aspect (1982) confirmed entanglement experimentally. That is, all objects are in a relationship of entanglement with each other, and this is a characteristic of atomic reality.

Is it possible that entanglement or non-locality could exist at the macroscopic level or between brains? Or to put it more boldly, might

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we be part of a brain network? Along with quantum non-locality, there is also biological non-locality (Josephson and Pallikari-Viras, 1991; Thaheld, 2010). Even though it was subjected to unjustified criticism when it was proposed, various studies have shown that there may be a non-local effect between brains (Grinberg-Zylberbaum, 1982; Grinberg-Zylberbaum and Ramos, 1987; Grinberg-Zylberbaum et al., 1994; Wackerman et al., 2003). Approximately 23 similar studies were carried out between 1963 and 2010, 20 of which hinted at a network, communication or effect between brains. In one of the most remarkable electrophysiological studies, the visual evoked potential (VEP) in a person (the sender) who was visually stimulated with a flash of light was able to transfer a similar wave to another person (the receiver) inside a Faraday cage and receiving no visual stimulus. This potential has been called transferred potential, and many other researchers have been able to make a transfer of up to 15 m under strict experimental conditions (Orme-Johnson et al., 1982). Even if the transfer is not always of a similar pattern to that created in the sender by the stimulus, it has at least been established that a simultaneous perturbation can take place in the brain of the receiver, which is above zero (Grinberg-Zylberbaum et al., 1994; Standish et al., 2004; Radin, 2004; Wackerman et al., 2003). In a similar way, a magnetic stimulus applied to the brain of a sender has successfully reached the brain of a receiver to whom no stimulus was applied (Persinger et al., 2008a; 2008b; Hu and Wu, 2006). In a similar manner to these studies, it was shown that a photic visual stimulus given to the sender created a simultaneous increase in the BOLD signal (an increase in blood flow) in functional MR of the occipital cortex of the receiver (Standish et al., 2003; Richards et al., 2005; Achterberg et al., 2005). What all these studies showed is that entanglement happened to a certain extent in certain situations and under certain conditions. In other words, what these findings showed is that the mind extends beyond the skull, and to a certain extent a brain network can be formed between empathic people (Korotaev et al., 2005).

6. Quantum psychopathology

A new window into the nature of mental illness may have opened with the recent publication of a symposium entitled "Quantum Paradigms of Psychopathology" (QPP), which appeared in a special issue of the NeuroQuantology Journal (2010). QPP's novel approach seeks a grounding of psychiatric disease in the counter-intuitive but physically foundational phenomena of the quantum micro-world within the brain. The relevance of physics on that small scale to sentient processes in the normal brain has been an ongoing subject of study since the closing decades of the last century.

The March 2010 on-line QPP symposium is the culmination of a related project that began in June 2008. At that time Donald Mender conducted an informal poll of participants in Quantum Mind, a series of conferences exploring the ideas introduced by Hameroff, Yasue, Vitiello, and others. Mender asked whether there exists among researchers any interest in the prospect of applying insights from Quantum Mind to aberrant processes underlying schizophrenia, bipolar illness, and other forms of psychopathology. The answer was a robust "yes". Nine fertile texts appeared in the resulting symposium. In his lead target article, Globus (2010) propounded a highly original concept of schizophrenia linked to the "tuning" of quantum vibrations suffusing the brain. Woolf and Tuszynski, offered credible links between psychopathology and quantum-computational dysfunction within the skeletal proteins giving shape to brain cells (Woolf et al., 2010). Pylkkänen related the physical substrates of mental illness to quantum "pilot waves" and analysed in detail the significance of Bohm's ontology for quantum paradigms of psychopathology (Pylkkänen, 2010). Mender himself proposed ways of comprehending the neurophysiology of disordered thinking and emotion in terms of quantum analogies to the freezing and melting of ordinary matter employing the language of quantum phase transitions and the quantum epistemology of Von Neumann, Wigner, and Stapp (Mender, 2010a; Stapp, 2001). Five commentators on these four target papers each introduced additional fresh quantum perspectives on the biophysical origins of psychopathology. A further commentary by Mender on this important monograph number of *NeuroQuantology* has been published (Mender, 2010b).

Theoretical researchers, including physicists Hiroomi Umezawa, Giuseppe Vitiello, Kunio Yasue, Paola Zizzi, Roger Penrose, Stuart Hameroff, Gordon Globus and Gustav Bernroider, have plumbed the depths of the sub-atomic structure and its macro amplifications to search for descriptions and interpretations of the interaction between the human brain and the software for the calculation of quantum algorithmic conscious phenomena (QPP Group, 2015). These seemingly unusual forms of data processing, as demonstrated by formal analysis provided by the discipline called "quantum computation", respond more accurately to many important attributes of the human psyche than the models derived from traditional cognitive neuroscience.

Both quantum-logical and quantum-physical models of brain and mind open new avenues towards a better understanding of neurobiology applied to psychopathology.For example, new explanatory and psychotherapeutic opportunities may emerge in the case of schizophrenic patients by considering Everett's quantum ontology in the "alternate worlds" of psychotic perception, "malattunement" in primary process thinking and "quantum logic". Similarly, in mood disorders such as Major Depression and Bipolar Disorder, the membrane and the biochemical relationships between serotonin, second messengers and "quantum microtubular nanowire" can be considered in order to understand the physical and molecular mechanisms at the base of these psychopathologies.

The aberrations of scale-dependent emergent phenomena during quantum thermofield phase transitions and other barriers to Bohmian holism may be important in multiple forms of mental illness.

Rudimentary phenomenal experiences occur even in the absence of complex synaptic connections among neurons as in the case of very simple organisms endowed with coherent water, "membrane lipid rafts" crucial for transmission to second messengers, ion channels and tubulin dimer in a state of quantum superposition within microtubules. In addition, quantum-biophysical aspects of other not yet mapped structures and related processes may be important factors in the deeper etiologies and may lead to improved treatment of psychiatric disorders.

6.1. Schizophrenia

In the paper "Quantum logic of the unconscious and schizophrenia" (Zizzi and Pregnolato, 2012a) the hypothesis that the logic of the unconscious is coextensive with the logic of schizophrenia was proposed. It might plausibly be argued that, while healthy minds employ both the classical logic of consciousness and the quantum primary process logic of the unconscious, schizophrenic minds use primary process thinking not only in their unconscious psychodynamics but also as their dominant conscious operating mode. The logics of both the unconscious and schizophrenic thinking were formalised and it was concluded that was the same logic.

At first, it was recognised that the sudden flashes of creative insight and other intuitive "leaps" arise from intermediate mental states that usually remain hidden from consciousness. These ultra-fast processes involving hidden intermediate stages are consistent with quantum computation.

The logic of the normal unconscious mind and the schizophrenic consciousness may therefore be Lq, or the logic of quantum information (Zizzi, 2010). For a healthy mind, the passage from the unconscious to the conscious state is determined by decoherence of qubits in the polymerised tubulins in microtubules, according to the OrhOR model of Hameroff and Penrose (1996). This may be understood in terms of very fast switches from the quantum logic of the unconscious to the classical logic of ordinary consciousness. It has been hypothesized that in schizophrenia these switches are not fast enough, and therefore the

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schizophrenic mind remains trapped too long in the unconscious logical mode.

In Lq, propositions are configured in qubits and the formal interpretation of the unconscious mind may potentially be understood as quantum-informational. The quantum concept of truth in the context of Lq is different from that of classical truth, to the extent that quantum truth manifests itself as many-valued (fuzzy) and is probabilistic, while on the contrary classical truth is single-valued and deterministic (Zizzi, 2013).

The metalinguistics of primary process thinking and the related psychopathological phenomena should be formalised by the quantum metalanguage (QML) with an appropriate application to schizophrenia, in which a surplus of quantum propositions dominates the classically logical discourse (Zizzi and Pregnolato, 2012b). In this context, it was possible to introduce the theoretical notion of the *Internal Observer* (*IO*) (Zizzi, 2005) a useful tool for developing a new type of therapy for schizophrenia.

6.2. Depression

Recently, Cocchi et al. (2012) conducted a biochemical experimental study on the content of fatty acids in the membrane of platelets from apparently healthy subjects, subjects with Bipolar Disorders (BD) and subjects with Major Depression (MD). The concentration data for the triplet of fatty acids (palmitic, linoleic and arachidonic acid) for each group of subjects considered were processed by an artificial neural network, called Self-Organizing Map (SOM) (Cocchi et al., 2008). Each subject showed a specific viscosity grade of the membrane, expressed by an index called B_2 (obtained from the sum of the percentages of the three acids considered, in relation to their molecular weights and their melting points). The distribution of the B_2 index in the one-dimensional map showed that the values of MD subjects (negative indices B_2) belonged to a completely separate area from that of healthy and bipolar subjects (positive indices B_2). Looking at the location of data on the SOM it was also found a region that had been attributed to subjects diagnosed as psychotic.

In order to build a theory describing these results, the language of set theory has been used. In this context, the set "Humankind" was considered as the Universal set, U. Then a bipartition was made of U in the cell A, in which all the elements are characterised by a positive value in cell B_2, while in the cell A^C, which is the complement of A in U, all elements are characterised by a negative value of B_2.

The spontaneous breaking of symmetry expected from the quantum field theory (QFT) is a possible theoretical explanation for why people with MD, with a negative value of the index B_2, fall into a category entirely separate from the rest of humankind. The B_2 value before the symmetry break is interpreted as the initial expected value, while the final B_2 values after the symmetry break can be read as the two expected values according to the well-known model used in QFT, the theory $\lambda\varphi 4$ (Itzykson and Zuber, 1986). The partition of the Universal set concerns set theory and equivalence relations in sets. The symmetry breaking, however, concerns classical and quantum field theories. These two seemingly unrelated aspects are unified by logic when the partition is a bipartition and the original symmetry is discrete Z_2 symmetry. The latter is equivalent to the logic gate "XOR", which is the logical conjunction of the two logic gates "NAND" (the negation of the conjunction of two propositions) and "OR". A bipartition is equivalent to the pair of the two logic gates "NAND", "OR" in which the "XOR" can be split. The logical connective "OR" plays an important role in the logic of human thinking, along with its double, the "AND". Instead, the "XOR" (ultimatum) seems to be more suitable for Artificial Intelligence (AI). In fact, the "XOR" is active only before symmetry breaking.

After symmetry breaking, we have the "OR", which is commonly used in the thinking done in our daily lives, whether or not it is supposed we belong to the equivalence class with a positive value of B_2, and the "NAND" that is not used. The "NAND" could then apply to the logic of subjects belonging to the other equivalence class with a negative value of B_2. This argument is supported by a series of experimental results about the reasoning ability of human subjects. In fact, the "NAND" can be rewritten as the disjunction of two negated propositions. Thus, MD subjects have a different logic from that of normal, bipolar and psychotic subjects. This also means that MD metalanguage is different and consists of negative assertions, which are a sign of pessimism and negative mood.

When negative assertions are the only possible ones, that is when you cannot switch to positive assertions (because only the logical connective "NAND" is available) then MD arises. In addition, it was found that MD subjects permanently use a quantum metalanguage (Zizzi, 2010) which is the negation of the quantum metalanguage permanently used by schizophrenics. The use of a (negative) quantum metalanguage was therefore suggested for the psychotherapy of MD subjects, as the use of a (positive) quantum metalanguage had been proposed for subjects with schizophrenia (Zizzi and Pregnolato, 2012a).

6.3. Future perspectives

A deeper study of consciousness-altering drugs and their binding to tubulin and microtubules may help us to understand the complex biological interface between conscious and unconscious states, and better understand the various forms of psychopathology in a deeper physical and meta-physical framework. The scientific research in this field should focus on the study of the quantum mind and brain, which are psychiatrically crucial instances of quantum logic and quantum physics respectively. In addition, scientists should directly test the behavioural aspects of thought-disordered subjects and analyse the results from a quantum point of view in order to design specific quantum technologies aimed at a clinical communication therapy. These considerations lead to the possibility of building a different approach for information; two possible complementary ways are the study of quantum gates on qubits and Licata's Hamiltonians with constraints. Qubits are more useful when we are interested in the identification of a specific state and show a natural affinity for the typical problems of nanotechnology. The geometric approach to the handling of quantum information is more fruitful when we try to study the global evolution of a system without forcing its non-local nature in any way. The latter mode of investigation clearly requires new tools based on formal dissipative QFTs (Licata and Minati, 2012).

7. A look at the future

What we call science is the systematisation of information obtained from nature. Nature has had its own laws from the beginning. Some of these laws are easy to express, while others stretch our understanding and even our sense of logic. Our efforts to understand nature and its workings, that is our production of scientific knowledge, will never end. We may never truly understand the workings of nature, or get close to the real truth. Therefore, it is ridiculous to behave as if we knew all of the workings of nature and to say "this is not scientific; it is in conflict with the (*known*) laws of science". The clearest example of this is when we see the workings of quantum physics in biological structures. When nature is working, it does not know the laws of our science and doesn't even take notice of them. Nature even sometimes winks at us with "anomalies". We learn from nature but we cannot impose on nature the laws we have learned from it.

Each theory set out in this article has its own acceptable points and deficiencies. Whatever our beliefs, theoretical ideas must be supported, and proof derived from experiment must be taken into account, with proof being strengthened by the same experimental method. If necessary, we must be brave enough to rewrite the physics textbooks. When Copernicus provided the proof that Man was not at the centre of the universe, the feeling that people were not privileged but just normal beings created great disillusion. Therefore, adding consciousness as

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a part of the solution to the measurement problem in quantum mechanics, as part of the approach which places humans back in a privileged position at the centre of the universe, is in conflict with these principles. Quite the opposite, the observer or experimenter, who is in such a privileged position, has set himself up as separate from the rest of the universe (the experimental apparatus, or what is outside us). The paradox is that if it is proved that we are participants in the universe, we will lose our last bastion of privilege, our position as experimenter, observer, or watcher. Such a proof would be the biggest revolution after Copernicus, and Darwin's theory of evolution.

Entanglement and non-locality in quantum mechanics and the entwinement of light and gravity in physics are proven but difficult-to-believe realities. In contrast, "*scientific*" physics journals and their archives publish hundreds of experimentally unsupported and completely theoretical articles on subjects which look more like science fiction. Among these are the M-theory, D-brane, wormholes, string theory, tachyons, superluminal communication, and the theory of everything. These are thought by many physicists to be within the scope of physical science, or at least are not greeted with antagonism. Involving consciousness in the experimental apparatus and researching that relationship is no more unnecessary than physical research in those border areas.

Another approach is that there is no necessity for people to be involved in quantum mechanics. Mathematical symbols denote the state vector or wave function, and there is no pace for metaphysics. The mathematical equations of quantum mechanics give us its measurements of potentiality, and potential measurements give potential results. That's all there is, and the rest is metaphysics. The approach that if one day humanity disappears, quantum mechanics will continue to operate its own laws is not scientific, but includes emotional attitudes. If equations are not a reflection of the physical world, we need to search for new equations. The operation of nature is not forced to conform to the laws of science, and moreover nature has never heard of science. Scientists have reduced the operation of nature to a simple form in order to understand it, and never produce scientific knowledge which reflects the actual truth. If nature under certain circumstances shows "abnormality" and ignores the laws which we have set up, we must be able to express that in scientific language. We cannot just bin an anomaly which has the potential to cause a revolution in our understanding of nature because it did not fit our scientific laws and equations, or because we could not find a valid law.

In the past 20 years, the attitude of "solid" physics and science to the results of studies of mind-over-matter effects and extrasensory perception has been to ignore them or to show contempt. Those who were better intentioned have found the methods of the studies to be wrong or biased, that the results were wrongly evaluated or that they were not sufficiently statistically significant. It went so far that it was even suggested that the p-value limit, the statistically significant 95% safety margin, should be changed in studies of mind and matter. When the use of eight tons a year of aspirin in the world is recommended to prevent heart attacks on the basis of this p-value, the same statistical effect is seen as insufficient in the case of research into mind-over-matter. This is a reflection of fear of a belief change. Can narrowing the gap between statistical values render meaningless the anomalous cases as they appear one by one? Your friend says he has a pig and that it can talk. You go to his house and the pig really can talk. In this situation, are you going to say you have to calculate the p-value, and unless there are more talking pigs you won't believe? Or would you say yes, there is the potential for talking in a pig's brain and try to understand the biological basis and what changes enabled it to talk? Whatever our personal beliefs, even if the proof conflicts with our most deeply held beliefs, we must show courage and pursue the truth.

There is one recurring theme of science. This is that resistance to change and the effect of change continually repeat themselves. Classical Newtonian physics, beginning in 1687, affected social life, other branches of science, and even the economy. In working life it has made everyone specialise and has forced everyone to work like machines. In social life it has shown individualism, and in art, Dadaism and cubism. In religion, the idea that 'God is dead' has taken root, because in a universe where everything is predetermined there is no need for a transcendental or regulating concept like God. The same physics produced Karl Marx's economic views based on class struggle; Adam Smith's self-managing liberal economy, Charles Darwin's theory of evolution and even Hitler's genocide policies. In psychology, it was the inspiration for Pavlov's dog and the development of intelligence testing. In the 400 years that Newton's physics ruled and afterwards, it was accepted that life was completely observable, measurable and convertible to numbers. Thus today, "solid" physicists, who oppose the reflection of quantum mechanics on social life, must acknowledge that the previous physics affected social life and even their own belief systems.

From ancient Greek times to the Middle Ages, it was considered for around 16 centuries that mathematics was a higher branch of learning than physics. This was because mathematics was based on firmer foundations and everything could be solved using only pen and paper, whereas physics carried out complicated experiments and made errors in measurement, giving inexact answers. As soon as the importance of experiments was understood, mathematics and physics joined forces, and started to produce results neither could have achieved alone. Today, physics is gaining the negative image previously acquired by mathematics, in face of research on the brain, the mind and consciousness. However if they join forces, both will have much to gain, and this must happen. Time will highlight the truth. Until that time, every piece of knowledge produced must be met with respect, interest and a spirit of enquiry.

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Please cite this article as: Tarlacı, S., Pregnolato, M., Quantum neurophysics: From non-living matter to quantum neurobiology and psychopathology, Int. J. Psychophysiol. (2015), http://dx.doi.org/10.1016/j.ijpsycho.2015.02.016

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Please cite this article as: Tarlacı, S., Pregnolato, M., Quantum neurophysics: From non-living matter to quantum neurobiology and psychopathology, Int. J. Psychophysiol. (2015), http://dx.doi.org/10.1016/j.ijpsycho.2015.02.016

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