Wireless Communication in the Brain: II. Quantum Information Processing

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Posted on: October 10, 2020

Abstract

This paper shows that the mind could use quantum bits (qubits) to encode and process information. These qubits are implemented by polarized electromagnetic waves (photons) emitted from ions as they pass through ion channels, similar to the electrons oscillating in an antenna. Experiments have demonstrated that the gravitational force plays a critical role in quantum entanglement and the formation of a Bose–Einstein condensate (BEC). The BEC has been proposed to overcome the decoherence problem in quantum computing. According to physical laws, the accelerated motion of ions in ion channels can also radiate gravitational waves which may facilitate quantum entanglement of qubits as well as the formation of BEC. In physics, the BEC of gravitational and electromagnetic waves is also known as a "geon" which could be the mind and the origin of consciousness.

Introduction

For decades, a few researchers have speculated that quantum-mechanical phenomena, such as wave interference and superposition, may play an important role in consciousness, but concrete evidence remains elusive. Moreover, two arguments were often raised against the quantum brain hypothesis (Jedlicka, 2017):

1. Neuronal signaling molecules, neurons and neural networks are **too large** to manifest wave natures.
2. The noisy, wet and warm environment will cause **decoherence** of quantum states within a tiny fraction of a second.

Specifically, Koch and Hepp (2006) wrote:

> *"Two key biophysical operations underlie information processing in the brain: chemical transmission across the synaptic cleft, and the generation of action potentials. These both involve thousands of ions and neurotransmitter molecules, coupled by diffusion or by the membrane potential that extends across tens of micrometres. Both processes will destroy any coherent quantum states. Thus, spiking neurons can only receive and send classical, rather than quantum, information. It follows that a neuron either spikes at a particular point in time or it does not, but is not in a superposition of spike and non-spike states."*

Although **the brain** is unlikely to be a quantum system, **the mind** could be. According to mind-body dualism, the mind is an immaterial substance distinct from the brain. Conscious perception of a scene is imprinted in the mind, not the brain. Thus,

the information about perceived scenes is stored in the **"mind"** whose physical nature remains to be elucidated. The electromagnetic (EM) waves do not occupy space. They are the immaterial substance. Furthermore, EM waves can encode information. They are widely used in mobile phones and other wireless communication systems. Therefore, the mind could comprise EM waves. Paper 1 has provided evidence for wireless communication in the brain from long-range neuronal synchronization. This paper will show that the mind could use quantum bits (qubits) to encode and process information. These qubits are implemented by EM waves (photons) which are known to exhibit quantum phenomena.

The Mind May Originate from Ion Channels

Since ancient times, humans have had the idea that the body may emit certain energy fields referred to as "aura" in Western countries and "qi" in China. The aura and qi are believed to be the EM fields in modern terminology. From 1978 to 1999, a large number of experts and scholars in China tested and analyzed the external qi of qigong. By using the dielectric-barrier discharge (DBD) method, they detected the EM waves emitted from the hand. The observed frequencies were found to be in the range 0.3-200 MHz (Zheng et al., 2016), with a median value at 10 MHz. The 10 MHz EM waves are generated most likely from neural activities. A human hand contains about 17,000 neurons, predominately concentrated in fingers (Delhaye et al., 2018). The commercial aura photography is also based on the energy fields emitted from the hand. Then, how can the neural activity generate 10 MHz EM waves?

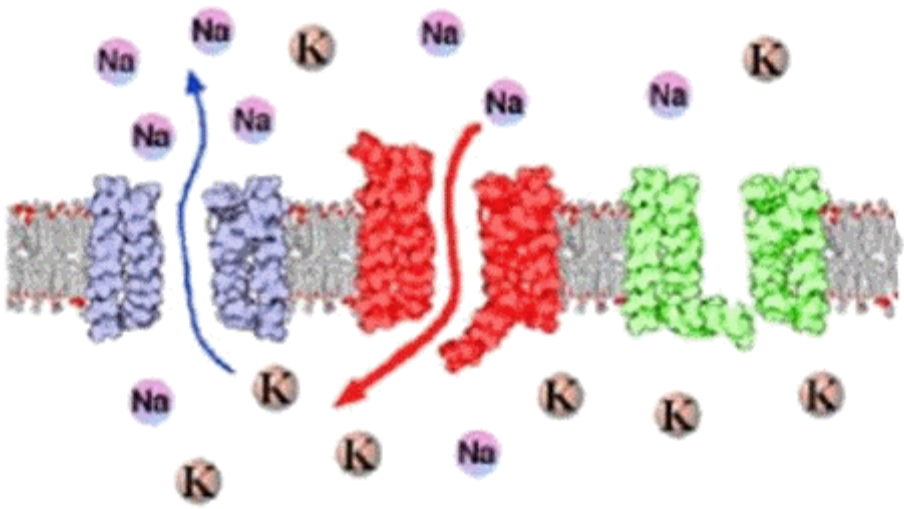

Figure 1. When a neuron fires, most ion channels are open, allowing ions (e.g., Na^+ and K^+) to pass through the channels, thereby producing electromagnetic (EM) waves. The ion channel thus resembles a straight antenna in which oscillating electrons generate polarized EM waves (photons).

Neuronal firing is accompanied by the opening of ion channels which are a special class of proteins embedded in nerve membrane. Physical laws dictate that any accelerating charged particle will radiate EM waves and any accelerating massive particle should produce gravitational (GR) waves. An ion has both mass and charge. Before ions enter ion channels, they move slowly and randomly in the solution, with negligible acceleration. As a neuron fires, a large number of ions will pass through the channels, with strong acceleration driven by the electrochemical gradient. Since ions possess both mass and charge, their accelerated motion will produce both GR and EM waves.

During the opening of a channel, a train of ions will pass through the channel one by one. Each ion will generate a pulse of EM energy. Thus, the frequency of EM waves emitted by these accelerated ions can be estimated from single channel currents. For voltage-gated sodium and potassium channels, the single channel current is about 1 - 4 pA (Aldrich and Stevens, 1987; Zagotta et al., 1988), where 1 pA = 10^{-12} ampere and 1 ampere = 6 x 10^{18} electron charge per second. Therefore, about 10^{7} ions can pass through a single channel within a second. The interval between two consecutive ions is then equal to 10^{-7} second, corresponding to a frequency of 10 MHz.

It is important to note that the value, 10 MHz, is obtained without any adjustable parameters. The value depends exclusively on single channel currents which are in the range 1 - 4 pA for major types of ion channels in neurons.

Qubits of the Mind Information

The "bit" is a basic unit of information in computing and digital communications. A "qubit" refers to the quantum bit in quantum information processing. Like the classical bit, a "qubit" also has two basis states, usually denoted as "0" and "1". However, qubits can exhibit quantum phenomena such as superposition between basis states and entanglement among qubits.

Any two-level quantum-mechanical system can be used as a qubit. In the past, most developers of quantum computers (e.g., Google and IBM) employed superconducting circuits to create a quantum system. Recently, a growing number of developers believed that the photon-based qubits (Slussarenko and Pryde, 2019) could be a more promising approach to quantum computing. An obvious advantage is that it can operate at room temperature, whereas the superconducting quantum computer must be maintained at the temperature near absolute zero.

Psi Quantum was founded in 2016, with the aim to build the first useful quantum computer by using silicon photonic qubits. This startup company has raised over $215 million. Another startup, Xanadu, raised $25M in 2018, $32M in 2019 and eyes $100M funding after it released world's first photonic quantum computer in the cloud on September 2, 2020. Psi Quantum claims: *"A useful quantum computer requires at least a million qubits.....Photonics is the only way to deliver 1,000,000 qubits."*

The photon can have two quantum states, depending on its polarization, which can be created by various methods. The most common method is the EM waves radiated from antenna (Figure 2). By convention, the state of polarization is based on the direction of the electric field. Thus, a vertical antenna (with respect to the Earth's surface) will generate vertically polarized photons while a horizontal antenna will generate horizontally polarized photons.

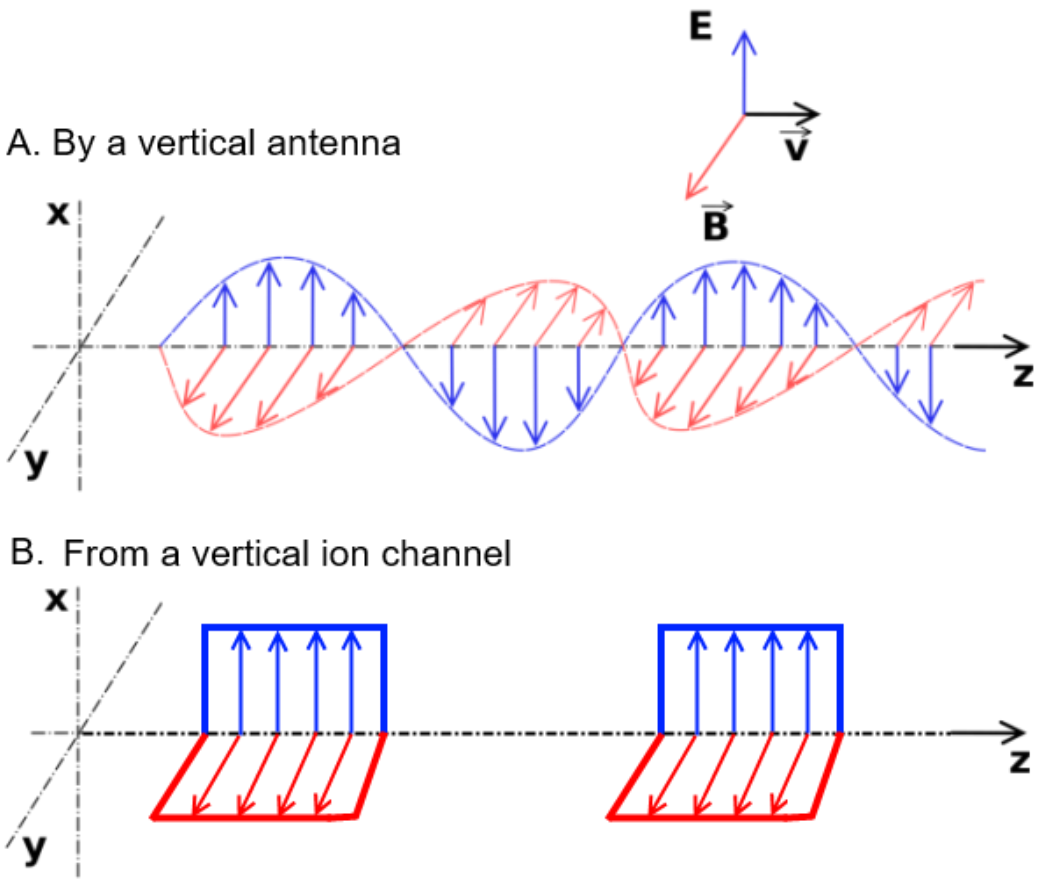

Figure 2. (A) The electromagnetic wave generated by a straight vertical antenna, producing vertically polarized photon. [Source: Wikipedia]
(B) The EM wave created by a train of ions passing through ion channels. A pulse is generated by an ion.

Intriguingly, the ion channel resembles a straight antenna in which oscillating electrons generate polarized EM waves (photons). Moreover, the mass of an ion (e.g., Na^+) is more than 10 thousand times the mass of an electron. Therefore, ions can

also radiate significant gravitational (GR) waves which may play an important role in overcoming decoherence.

How the Mind Overcomes Decoherence

Decoherence is a phenomenon in which the interaction between qubits and the environment limits the coherence time so that the information stored in qubits is lost rapidly. For instance, the coherence time of a photon pair from a laser beam is only about 40×10^{-15} second that can be increased to 350×10^{-12} second by narrow filtering (Halder et al., 2007). In contrast, the duration of a nerve impulse is about 10^{-3} second. Thus, for photons to implement qubits, their coherence time must be several orders of magnitude longer than the photon pair in a laser beam.

Figure 3. Observation of entangled photons by using single-photon-sensitive intensified cameras. Note that in most cases the two photons appear together either on the left or right side, reflecting their entanglement (coherence).
[Source: Wikipedia]

Quantum entanglement is a type of coherence. Entangled photons have been directly observed (Figure 3). EM waves are known to travel at the speed of light, that is, approximately 300,000,000 meters per second. Within a tiny fraction of a second, the emitted EM waves would have moved far away from the source. Then, how can photons bunch together?

There are only four fundamental forces in our universe: gravitational, electromagnetic, strong and weak nuclear forces. Photons do not exert nuclear forces. They do not carry charges and thus cannot attract each other through electromagnetic interaction. Thus, only the gravitational attraction is possible to mediate their entanglement or coherence. We know that any two masses can attract each other via gravitational interaction. Recently, the gravitational force has been shown to induce quantum entanglement and coherence between massive particles (Marletto and Vedral, 2017; Krisnanda et al., 2019; Ghoshal et al., 2020). A photon is massless, but it has an energy of hv, where h is the Plank's constant and v is its frequency. Through Einstein's famous equation, $E = mc^2$, the photon also has an effective mass which can exhibit gravitational interaction. Such GR force is very weak, unable to induce the entanglement of a large number of photons. To date, less than 20-photon entanglement has been observed (Wang et al, 2016; Zhong et al., 2018).

The Bose–Einstein condensate (BEC) has been proposed to overcome the decoherence problem in quantum computing (Tim Byrnes; Georgia Tech News, 2013). A BEC is the lowest quantum state of a group of bosons (with integer spin), such as rubidium, sodium and photons. When a gas of boson atoms are cooled to temperatures very close to absolute zero (-273.15 °C), microscopic quantum mechanical phenomena, particularly wavefunction interference, become apparent macroscopically, thereby causing them to bind together (see this article).

Unlike atoms, a photon is massless. However, it possesses energy and thus has an effective mass which, under normal conditions, is too small to induce the formation of a BEC. In 2010, Klaers et al. managed to create the BEC of photons by confining photons in a dye-filled optical microcavity to increase effective mass. This finding underscores the importance of gravitational force in the formation of BEC.

The coherence of an interacting two-component BEC can survive for seconds (Egorov et al., 2010). Therefore, ideally, quantum information processing should employ BEC to prevent rapid decoherence. More than three decades ago, it has been suggested that consciousness could arise from the formation of BEC based on its unity, complexity and non-locality (Marshall, 1989). From the viewpoint of quantum information processing, the mind should also be a BEC.

Creation of the Mind BEC

As discussed above, the ions passing through ion channels may emit both EM and GR waves. Due to weak gravitational attraction between EM waves (photons), they cannot form a BEC by themselves. However, GR waves are the carrier of gravitational force. The attractive force between GR waves, or between GR and EM waves, is strong. It has been estimated that the GR-GR attractive force is more than 80 orders of magnitude stronger than the EM-EM attraction (Faraoni and Dumse, 1998, Eq. 6.1).

The frequency of EM and GR waves generated by ionic flux is estimated to be about 10 MHz, corresponding to the wavelength of 30 meters which is much larger than the size of a brain. Thus, the entire brain can be considered as a point at which synchronized GR and EM waves should produce constructive interference. If the number of synchronized GR/EM waves is sufficiently large, the BEC of GR/EM waves can be created (Figure 4).

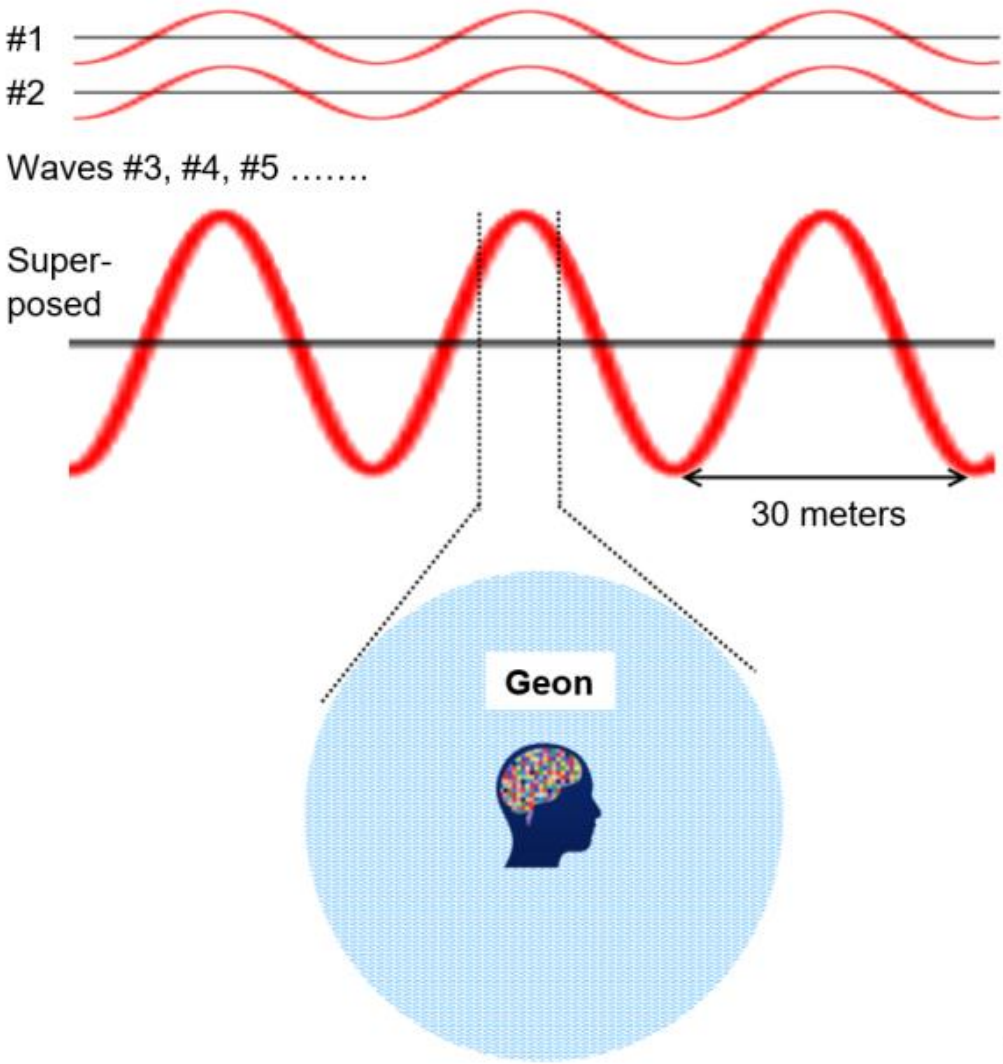

Figure 4. The BEC of GR/EM waves (a geon) can be created by constructive interference among a large population of synchronized GR/EM waves that are emitted from the ions passing through ion channels during synchronized neuronal firing.

In physics, the term "geon" refers to an entity consisting of only GR and/or EM waves which are held together in a confined region by their mutual attraction. Thus, the BEC of GR/EM waves

can also be called a geon. Neuroscientific studies suggest that the geon is formed by synchronized neuronal oscillations at the alpha band. Physiological information from sensory inputs and memory retrieval is not encoded in alpha rhythms, but in the θ-nested-γ pattern (see this chapter).

Summary

Recently, a growing number of developers believed that the photon-based qubits could be a promising approach to quantum computing (Slussarenko and Pryde, 2019; Psi Quantum; Xanadu). This paper shows that the mind could indeed use photons for quantum information processing. To overcome the decoherence problem, gravitational waves are also required to facilitate photon entanglement and the formation of a Bose–Einstein condensate (BEC). Thus, the mind should be a BEC of GR/EM waves, also known as a geon. The GR/EM waves of the mind may originate from the radiation of ionic flux through ion channels. This notion is supported by the consistency between estimated frequency (~ 10 MHz) and experimental observation (Zheng et al., 2016).