Original Article

Conscious Electromagnetic Field Theory

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Abstract

The conscious electromagnetic field theory (CEMI field theory) is described which proposes that consciousness is a manifestation of the brain's electromagnetic (EM) field. The key feature of the brain's EM field is that it is capable of integrating vast quantities of information into a single physical system and it thereby accounts for the binding of consciousness. The CEMI field theory is shown to be compatible with all the known facts about consciousness. Unlike quantum theories of consciousness, the CEMI field theory does not require any special physical states in the brains; it is perfectly compatible with brain physiology. Nevertheless, recent work has shown that classical electromagnetic waves may be used to implement quantum algorithms; therefore the brain's CEMI field may be able to perform quantum computations (but without the requirement for quantum coherent states of matter).

Key Words: electromagnetic field, consciousness, brain-mind problem, CEMI field theory

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1. Field Theories of Consciousness

The idea that our conscious minds are some kind of field goes back at least as far as the gestalt psychologists of the early twentieth century. Gestalt psychology emerged in opposition to the contemporary atomist movement, which claimed that perceptual experience is merely the sum of simple sensory inputs. The gestalt psychologists instead emphasized the holistic nature of perception which they claimed was more akin to fields, rather than particles. In this they were influenced by the ideas coming out of newly emerging science of quantum mechanics (indeed, Wolfgang Köhler, one of the gestalt pioneers, studied with Max Planck, the founder of quantum mechanics). Fields share the holistic qualities of perceptual fields described by the gestalt psychologists but the Gestalt psychologists went on to propose that physical fields exist in the brain that are isomorphic to the objects they represented, in the sense that the had the same shape as the represented object.

It was the proposal that the brain contains real physical fields that correspond to perceived objects (as Kohler described it, that the brain acts as a "physical Gestalt") that led to the virtual abandonment of Gestalt psychology in the late 1950s. Modern neurobiology defined the neuron as the fundamental computational unit in the brain and there didn't appear to be any way of forming isomorphic Gestalt fields out of static neurons. But although much of what the brain does can be understood in terms of standard neuronal theory, the peculiar features of consciousness led many retain the concept of a field in order to account for these properties. Karl Popper (Popper et al., 1993) proposed that consciousness was a

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manifestation of some kind of overarching force field in the brain that could integrate the diverse information held in distributed neurons. The idea was further developed and extended by Lindahl and Århem (Lindahl and Arhem, 1994) and by Libet (Libet, 1996; Libet, 1994). However, these authors considered that the conscious mind could not be a manifestation of any known form of physical field and its nature remained mysterious. Yet it has been known for more than a century that the brain generates its own electromagnetic (EM) field, a fact that is widely utilized in brain scanning techniques such as EEG. Electrical coupling via electromagnetic field effects have been suspected to play a role in a number of neurological phenomena, particularly the generation of synchronous waveforms in neural assemblies and in epilepsy (Gluckman et al., 1996; Jefferys, 1995).

In two papers published in 2002 I described the conscious electromagnetic field theory (McFadden, 2002b; McFadden, 2002a), which was an extension of the CEMI field theory outlined in my book "Quantum Evolution" (McFadden, 2000). The theory has much in common with the EM field theory of consciousness proposed by Dr Susan Pockett in her book "The Nature of Consciousness: A Hypothesis" (Pockett, 2000). The neurophysiologist E. Roy John has also published a theory of consciousness involving EM fields (John, 2002). The key insight of these theories is the realisation that, as well as generating chemical signals that are communicated via conventional synapses, neural firing also generates perturbations to the brain's EM field.

2. The Brain's EM Field

At rest, the neuronal membrane forms a dipole in which the inside of the membrane is negatively (about -65 mV) charged in relation to the outside of the membrane. This charge difference is maintained by the action of ion pumps that pump cations (principally sodium and calcium) out of the neuron. Brain neurons are densely packed, with about 10^4 neurons/mm^2 so the fields of adjacent neurons will not be discrete but form a complex overlapping field made up of the superposition of the fields of millions of neurons in the vicinity.

When any neuron receives a signal from upstream neurons, synaptic transmitters stimulate ion pumps that cause the membrane to become more or less negatively polarized, depending on the type of signal received. If the membrane charged falls below about 30mV then the neurons "fires" and a chain of depolarization is triggered that travels along the neuron and stimulates release of neurotransmitter. Conventional neurobiology has focused on the chemical signal that is transmitted from one neuron to another. There is absolutely no doubt at all that most of the information processing performed by the brain is due to this type of signaling. However, the massive membrane depolarization will also generate an EM field perturbation that, traveling at the speed of light, will influence the probability of firing of adjacent neurons. Vigmond (Vigmond et al., 1997) modeled the electrical activity of pyramidal cells and demonstrated that neuron firing induced a peak of intracellular potential in receiver cells that ranged from a few microvolts to 0.8mV, decaying with approximately the inverse of distance between the cells.

The electrical field at any point in the brain will be a superposition of the induced fields from all of the neurons in the vicinity (superimposed on the fields generated by ion movement) and will depend on their firing frequency, geometry and the dielectric properties of tissue. For neurons that are arranged randomly, their induced fields will tend to sum to zero; but the laminar organization of structures such as the neocortex and hippocampus, with parallel arrays of neurons, will tend to amplify local fields. Although it is not feasible to calculate the local field strength at any point in the brain without precise knowledge of all the structures, estimates of its magnitude can be gained experimentally. Extracellular potentials with peak intensities of several hundred microvolts up to about one millivolt across the recording electrodes are routinely obtained (Niedermeyer, 2001; Quesney and Niedermeyer, 1998). Local field potentials have also been measured in the neocortex of experimental animals with implanted electrodes and demonstrate extracellular field gradients of up to about 20V/m (Engel, 1998; Amzica and Steriade, 2000; Gray, 1994; Jefferys, 1995). Measurements made on hippocampus brain slices maintained in vitro record field potentials as high as 50100V/m (Jefferys, 1981; Green and Petsche, 1961; Swann et al., 1986).

3. The Influence of the Brain's EM Field on Neural Firing.

The field across a neuronal membrane will inevitably be the product of the field generated by membrane dynamics (the ion pumps) but also the fields generated by the resting states and firing of all the other neurons in the vicinity. Mostly the influence of the external fields will be quite weak – may be up to a millivolt across the membrane - and so will only be capable of influencing the probability of firing if the neural membrane is already close to the critical firing potential. However, in a busy brain it is very likely that many neurons will be in that state, so the EM field that the brain's activity generates will inevitably influence neural dynamics. This will create a self-referring feedback loop that, I propose, is the physical substrate of consciousness.

Unfortunately investigating the role of the brain's endogenous EM field on information processing in the brain presents huge experimental challenges, as it is not possible to turn the EM influence off and on (nerve firing always generates m field perturbations). But indirect evidence for the proposal that the brain's endogenous field plays a role may be gained from studies of the effect of external fields on neural activity. In humans, the strongest evidence for the sensitivity of the brain to relatively weak EM fields comes from the therapeutic use of transcranial magnetic stimulation (TMS). In TMS, a current passing through a coil placed on the scalp of subjects is used to generate a time-varying magnetic field that penetrates the skull and induces an electrical field in neuronal tissue. The precise mechanism by which TMS modulates brain activity is currently unclear but is generally assumed to be through electrical induction of local currents in brain tissue that modulate nerve firing patterns. TMS has been shown to generate a range of cognitive disturbances in subjects including: modification of reaction time, induction of phosphenes, suppression of visual perception, speech arrest, disturbances of eye movements and mood changes (Hallett, 2000). Even single TMS pulses have been shown to induce spreading changes to the brain's electrical activity, which can be detected by EEG or MEG and persists for many milliseconds after stimulation (Ilmoniemi et al., 1997; Ilmoniemi et al., 1999), once again indicating that neuronal firing patterns have been modulated. The field induced in cortical tissue by TMS cannot be measured directly but may be estimated from modeling studies. The evoked field depends critically on the instrumentation, particularly the coil geometry and strength and frequency of stimulating magnetic field. In one study where stimulation utilized a set of four coils, the induced electrical field was estimated to be in the range of 20 - 150 V/m (Epstein et al., 1990), (Ruohonen et al., 2000). TMS voltages are thereby in the range of tens of volts per metre, values that are typical for the strength of the brain's endogenous EM field. Therefore, since TMS induced modulations of the brain's EM field affect brain function and behavior, it follows that the brain's endogenous field must similarly influence neuronal computation.

There is also very solid in vitro evidence for very weak EM fields modulating neuronal function. Fields as weak as 10-20V/m have been shown to modulate neuron-firing patterns of Purkinje and stellate cells in the isolated turtle cerebellum in vitro (Chan and Nicholson, 1986) or the guinea-pig hippocampus (Jefferys, 1981). Electric field suppression of epileptiform activity in rat hippocampal slices has been demonstrated for fields as low as 5-10V/m (Gluckman et al., 1996) and modulation of hippocampal rhythmic slow activity in rats has been demonstrated in vivo by weak extremely-low-frequency (ELF) magnetic fields (16.0 Hz; 28.9 microT) associated with induced electrical fields of only 10-4V/m (Jenrow et al., 1998). A molluscan neuron has been shown to be capable of responding to earth-strength (about 45 microT) magnetic fields (Lohmann et al., 1991), associated with induced electrical fields of just 2.6 x 10-4 V/m.

4. The CEMI Field Theory

It is clear that very weak EM field fluctuations are capable of modulating neuron-firing patterns. These exogenous fields are weaker than the perturbations in the brain's endogenous EM field that are induced during normal neuronal activity. The conclusion is inescapable: the brain's endogenous EM field must influence neuronal information processing in the brain. Information in neurons is therefore pooled, integrated and reflected back into neurons through the brain's EM field and its influence on neuron firing patterns. This self-referral loop has physical and dynamic properties that precisely map with consciousness and are most parsimoniously accounted for if the brain's EM field is in fact the physical substrate of consciousness and conscious volition results from the influence of the brain's EM field on neurons that initiate motor actions. The conscious electromagnetic information (CEMI) field theory thereby proposes:

> "Digital information within neurons is pooled and integrated to form an electromagnetic information field. Consciousness is that component of the brain's electromagnetic information field that is downloaded to motor neurons and is thereby capable of communicating its state to the outside world."

The CEMI field theory suggests that processing information through the wave-mechanical dynamics of the CEMI field provided a significant advantage to our ancestors that was captured by natural selection to endow our minds with the capability to process information through fields. MacLennan (MacLennan, 1999) has proposed that the brain is capable of field computing (which has many of the attributes of quantum computing) that may perform some operations with greater efficiency, or with fewer resources, than can be achieved in a digital system. In a similar way, optical holograms can perform convolution, deconvolution and Fourier transforms, at the speed of light, acting on massively parallel data sets. Sending information through the EM field may similarly confer novel information processing capabilities on the human brain that have been captured by our conscious mind.

5. Why Don't External Fields Influence Our Minds?

The high conductivity of the cerebral fluid creates an effective 'Faraday cage' that insulates the brain from most natural exogenous electric fields. A constant external electric field will thereby induce almost no field at all in the brain (Adair, 1991). Alternating currents from technological devices (power lines, mobile phones, etc.) will generate an alternating induced field, but its magnitude will be very weak. For example, a 60Hz electrical field of 1000 V/m (typical of a powerline) will generate a tissue field of only 4x 10^{-5} V/m inside the head (Adair, 1991), clearly much weaker than either the endogenous em field or the field due to thermal noise in cell membranes. Magnetic fields do penetrate tissue much more readily than electric fields but most naturally encountered magnetic fields, and also those experienced during nuclear magnetic resonance (NMR) scanning, are static (changing only the direction of moving charges) and are thereby unlikely to have physiological effects. Changing magnetic fields will however penetrate the skull and induce electric currents in the brain. However, there is abundant evidence (from e.g. TMS studies as outlined above,) that these do modify brain activity. Indeed, repetitive TMS is subject to strict safety guidelines to prevent inducing seizures in normal subjects (Hallett, 2000) through field effects. High frequency electric fields generated by cellular (mobile) phones would be expected to penetrate the head more effectively (limited by the electromagnetic skin depth - the distance in which the field is attenuated by a factor of e^{-1} - which for the head is about one centimeter) but their high frequencies (in the MHz or GHz range) make them unlikely to interact with low brain frequency waves.

Note however that although external fields are seldom able to influence nerve dynamics, this will not be true for endogenous fields. Indeed, the fact that EEG signals can be detected on the scalp indicates that endogenous EM fields do penetrate brain tissue. The reason for this is that the major source of EEG signals (and more generally, the brain's EM field) is not the firing of single neurons but assemblies of neurons firing synchronously (as discussed in my earlier paper). By firing in synchrony, neurons distribute and amplify field effects.

6. How The CEMI Field Theory Accounts For The Essential Features Of Consciousness

Consciousness generates phenomena in the world. It is a cause of effects. A distinctive feature of the CEMI field theory is the proposal that consciousness corresponds to only that component of the brain's EM field that impacts on motor activity. This does not imply that the brain's EM field acts directly on motor neurons (which may of course be located outside the brain) but only that EM field information is communicated to the outside world via motor neurons. The site of action of the brain's EM field is most likely to be neurons in the cerebral cortex involved in initiating motor actions, such as the areas that control speech, or the areas involved in laying down memories that may later be reported via motor actions (such as speech). Indeed, there is good deal of evidence (see e.g. (Aarons, 1971; Paulesu et al., 1993) that all verbal thought is accompanied by subvocalisations (i.e. motor cortex activity accompanied by appropriate but normally undetectable vocal tract activity). This informational download via the brain's EM field avoids the pitfalls of most other field theories of consciousness that either suffer the classic "mind-matter problem" (a non-physical consciousness whose interaction with the matter of the brain is left unresolved) or leave consciousness as a ghost in the machine (somehow generated by the brain but with no impact on its workings).

Consciousness is a property of living (human) brains. As far as we know, it is not a property of any other structure. The only place in the known universe where EM fields occur that are capable of communicating self-generated irreducibly complex concepts like "self" (and thereby persuading an observer that they are indeed conscious) is in the human brain. Artificially generated EM fields, such as the EM fields that communicate radio and TV signals, are only capable of communicating the information encoded and transmitted within their fields. They have nothing else to say. To question whether they are either aware or conscious is meaningless.

Brain Activity May Be Conscious/Unconscious

Neurons in a complex brain display a range of excitability and in the busy brain of our ancestral animals there would have been many neurons poised close to their threshold potential with voltage-gated ion channels sensitive to small changes in the surrounding EM field. No less than electrochemical interactions, those field interactions would have been subject to natural selection. Wherever field effects provided a selective advantage to the host, natural selection would have acted to enhance neuron sensitivity (e.g. by maintaining neurons close to firing potential, increasing myelination or orientating neurons in the field). Conversely, wherever field influences were detrimental to the host (e.g. providing an EM field 'feed-back' that interfered with informational processing), natural selection would have acted to decrease that sensitivity (e.g. by maintaining neurons at membrane voltages close to resting). Therefore, with just the information that the brain's EM field influences informational processing (as I have shown it must) and thereby affects host survival, the theory of natural selection predicts that over millions of years a complex brain will evolve into an EM field-sensitive system and a parallel EM field-insensitive system: our conscious and unconscious minds.

The unconscious mind can perform parallel computations but consciousness can only do one thing at a time. If conscious actions involve the influence of an EM field - the CEMI field - on neural pathways, then this interference is entirely explicable. Unlike digital (neural) addition, summation of two fields generates a linear superposition that depends on the phase relationships between the individual waves involved. Interference is therefore inevitable for conscious multiple tasks that require the influence of the CEMI field.

Information that is encoded by widely distributed neurons in our brain is somehow bound together to form unified conscious percepts.

Information in the conscious brain is encoded in the firing rates of billions of neurons scattered across the entire surface of the cerebral cortex. However, that information will be reflected into the EM field that permeates the cortex. In contrast to the discrete and distributed information encoded in the neurons, the field-based information is always unified. Fields unify information. That is what we mean by a field. The brain's EM field has the same level of unity as a single photon. From the reference frame of an outside observer, a field is a continuum of values (information) extended in space and time. However, from the reference frame of the field, there is neither space nor time between any part of the field or any bit of its information. This can be appreciated by following Einstein in imagining hitching a ride on the back of a photon. Because photons travel at the speed of light and time slows down to stop at this speed, it takes no time at all for the photon to travel from its point of creation to its point of annihilation - it is everywhere at once. So all of the information contained in the field is everywhere at once, bound into a single dimensionless point. The CEMI field theory proposes that our consciousness resides in that dimensionless point. Consciousness and awareness are associated not with neural firing per se but with neurons that fire in synchrony.

The superposition principle states that the EM field at any point is a superposition of the component fields in the vicinity of that point. Like all wave phenomena, field modulations due to nerve firing will demonstrate constructive or destructive interference depending on the relative phase of the component fields. Temporally random nerve firing will generally generate incoherent field modulations leading to destructive interference and zero net fields. In contrast, synchronous nerve firing will phase-lock the field modulations to generate a coherent field of magnitude that is the vector sum (the geometric sum - taking into account the direction of the field) of its components. The number of cells involved in synchronous firing is thought to vary widely but in EEG, synchronization of cortical beta and gamma rhythms can be detected between pairs of electrodes at inter-electrode distances of 40mm, indicating that synchronization may involve very many spatially-distributed neurons (Lopes da Silva, 1998; Bullock et al., 1995). So, whereas a single neuron may influence several hundred neighboring neurons through field effects, synchronous (but not asynchronous) firing of clusters of neurons will generate perturbations of the brain's EM field that will influence many millions of distributed neurons. Synchronous firing amplifies EM field effects by phase-locking EM field modulations generated by distributed neurons. The brains' EM field - where consciousness is proposed to reside in the CEMI field theory - will reflect the informational content of synchronized neurons far more than desynchronized neurons. Synchronous firing will thereby be a correlate of consciousness.

7. A Criticism of Quantum Theories of Consciousness

The brain's EM field is the natural substrate for field-based theories of consciousness. There is however a great deal of interest in the possibility of quantum matter fields in the brain and several theories of consciousness have proposed quantum coherence of states of matter in the brain, such as putative 10 GHz oscillations in the dimerisation state of microtubule proteins, as a means of integrating neural information and performing quantum computing in the brain. However, whereas there is no doubt that electromagnetic fields exist in the brain there is no convincing evidence for large-scale quantum coherence of matter in the brain and very real theoretical problems with understanding how quantum coherence in microtubules could possibly be maintained for timescales longer than picoseconds (Tegmark, 2000). Although these conclusion have been challenged (Hagan et al., 2002) the difficulty in maintaining quantum coherence in order to perform quantum computing with just a few atoms maintained at a temperature close to absolute zero (Fisher, 2003) is evidence to the implausibility of maintaining quantum coherence for physiologically relevant periods of time in a warm wet brain. Note however that this issue is quite distinct from that of a quantum treatment of the electromagnetic fields of the brain, which is a natural complement to the CEMI field theory. I identify here four additional problems with the concept of quantum (matter) fields being a substrate for consciousness in the brain:

A. Although phenomena such as change blindness and intentional blindness indicate that we are aware of far less than we imagine, information in consciousness is undoubtedly complex and must be encoded by a physical informational substrate capable of encoding a complex message. Quantum consciousness theorists who propose that the physical substrate of consciousness is some kind of quantum state of matter, such as a Bose-Einstein condensate (BEC), often ignore this requirement. Even if it were physically feasible to maintain a BEC in a hot wet brain, such a state would be an unlikely substrate for consciousness because all the atoms in a BEC are in the same quantum state and thereby encode the same information. Quantum states are nearly always small and simple because as they get larger and more complex, it becomes harder to maintain all the information in a coherent state: the system decoheres. And although, in principle, a single qubit (the unit of quantum information) stores an infinite quantity of information (as virtual bits in its Hilbert space representation), in practice this is extremely difficult to exploit because decoherence becomes more likely as the complexity of the system increases and thereafter the qubit is reduced to a classical bit. This is why quantum computation is so difficult (and why only very simple calculations have so far been performed with qubits). And it is why quantum states of matter are unlikely substrates of information-rich consciousness in a hot wet brain.

B. Consciousness is continuous but temporally dynamic: contents of consciousness change on a timescale of milliseconds or less. The substrate of consciousness must therefore be similarly dynamic. However, dynamic quantum states of matter (such as the putative gigahertz oscillations of microtubule protein) decohere in nanoseconds or less (Tegmark, 2000). Quantum states of matter could therefore not remain coherent for long enough to encode the continuity of thought.

C. Consciousness exchanges information with the world. Whether this informational exchange is one way or in both directions depends on whether consciousness has a causal influence on the world. Although I will not here advance any arguments to support the claim of the CEMI field theory that consciousness has a causal influence on our actions (see my earlier papers for such arguments), I will only note that any scientific theory of consciousness must support some causal influence on the world, since science can only study phenomena that have effects. This property is incompatible with large-scale coherence of matter as the substrate of consciousness, since information exchange of a quantum state with its environment is precisely what causes decoherence. It is simply not physically possible to maintain coherence within a large-scale quantum system if it is freely exchanging information with its environment.

D. For quantum mechanics to account for binding, the microtubules must be entangled not only within single neurons but also across the many thousands of scattered neurons that encode conscious information. This is proposed to take place through “microtubule quantum states [that] link to those in other neurons and glia by tunneling through gap junctions (or quantum coherent photons traversing membranes)” (Hameroff, 2001). However, a knock-out (KO) mouse has recently been generated which lacks the connexin-36 (Cx36) subunit of the principle gap junctions thought to be mediating neuronal electrotonic coupling mammalian brains (Guldenagel et al., 2001; Buhl et al., 2003). As expected, the connexin-36 KO mouse lack gap junctions and therefore lacks many (if not all) of the proposed sites for the putative inter-neuron quantum tunneling. Yet, the KO mice “showed no obvious behavioral abnormalities” (Guldenagel et al., 2001). The findings indicate that, if gap junctions are the site for tunneling of microtubule quantum states, then the process appears to play no obvious neurophysiological role, at least in mice. And although the question of whether mice are conscious is obviously a matter of conjecture, it would seem unlikely that a neurophysiological role for microtubules in man (information processing) could be completely absent in mouse. The lack of an obvious behavioral phenotype of the Cx36 mice undermines a central claim of the microtubule quantum consciousness theory. Interestingly, the Cx36 KO mice provide evidence that supports the CEMI field theory proposal that EM fields are the substrate for conscious binding. Synchronous neuronal firing is known to be a correlate of attention and awareness and fast transmission of signals though gap junctions has previously been proposed to mediate synchrony. However, high frequency synchronous neuronal oscillations are still observed in the Cx36 KO mice (Hormuzdi et al., 2001), indicating that other mechanisms (such as EM fields) may be involved in maintaining synchrony and thereby potentially providing a substrate for conscious binding.

8. Quantum Computing Can Be Performed By Classical Fields

MacLennan (MacLennan, 1999) has proposed that the brain is capable of field computing (which has many of the attributes of quantum computing) that may perform some operations with greater efficiency, or with fewer resources, than can be achieved in a digital system. In a similar way, optical holograms can perform convolution, deconvolution and Fourier transforms, at the speed of light, acting on massively parallel data sets. It has recently been generated that classical waves, such as light waves (which are of course electromagnetic waves) can implement quantum mechanical algorithms, such as the Grover quantum search algorithm, just as efficiently as a quantum system (Bhattacharya et al., 2002). There is therefore no need to propose physically unrealistic quantum coherence of matter in the brain to perform quantum computing. The brain's EM field, the CEMI field, is capable of performing quantum computing in the brain.

Conclusions

Analogue computers were built alongside the first digital computers, with machines like the differential analyzer developed by Vannevar Bush at MIT in the 1950's, which performed mathematical operations by converting equations into a configuration of rotating shafts and gears (an isomorphic transformation). Despite their success in efficiently performing the operations for which they were designed, they were rapidly superseded by their digital counterparts. This was primarily because, compared to digital computers, they were so hard to program. The logic of their calculations was built into their structure (as intrinsic information) so changing the program amounted to changing their structure. For the differential analyzer, this meant that each calculation needed a different arrangement of shafts and gears, obviously a much more cumbersome transformation than reprogramming a digital computer. However, the architecture of the brain is far less rigid than a mechanical device and its structure is constantly changing under the influence of both individual experience and evolutionary pressure. It may not be easy to engineer a flexible analogue computer, but it may be possible to evolve one. I propose that our conscious mind is such a device - a flexible analogue computer evolved out of the neuronal architecture of the brain that uses the brain's EM field or CEMI field (McFadden, 2002a; McFadden, 2002b) to process information. Such a computer may be capable of implementing quantum algorithms to perform quantum computing without the need for physically unrealistic quantum states in the brain.

As proposed in my earlier papers, awareness may be a property of information experienced from the frame of reference of the physical substrate encoding information. Just as magnetic and electrical forces are properties of the same system (electromagnetism) experienced from different frames, so awareness and information may be two aspects of the same system - an EM field - experienced from an inner or outer frame of reference. However, it is important to emphasize that the CEMI field theory does not propose that the whole brain is involved in this type of information processing. There is little doubt that most of what the brain does - all of the unconscious operations that performed by the brain-is achieved through the actions of neurons, action potentials and synaptic transmission -digital and symbolic computing. But, as argued in my earlier papers, such a system cannot account for consciousness. The CEMI field theory accounts for all the essential features of consciousness. It is compatible with physical theory and brain physiology and, unlike quantum theories of consciousness; it requires neither special states of matter nor unlikely combination of physical parameters. The CEMI field theory suggests that consciousness is what electromagnetic field information feels like from the inside.

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