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Research Article

Proper Understanding of the Neurons as Generators of electric Power and Potential of the Nerve Impulses

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Abstract

Measuring an induced magnetic field by the flow of electric charges through axons and understanding the neuroscientific definition of the flow of nerve impulses through axons as electric signals led to introduce the Volume Conduction (VC) model that defines the axons as electric conductors. According to a new definition of the electric charges as electromagnetic (EM) waves that have an electric potential, we modify in the present study the VC model by a definition of the nature of the nerve impulses as electric charges. In previous studies were recorded the brain waves as EM waves and brain's consumption of the body's metabolic heat was estimated as 20% while its mass is less 2% of the human body. According to such results, we concluded the brain neurons are acting as generators of the charge of the nerve impulses which consumes the metabolic heat and emitted EM waves from the brain. This conclusion confirms the nature of the nerve impulses as EM waves and found a source of the flowing energy through axons as electric charges. Recognizing a difference of temperatures and the Seebeck coefficients across the neuron's membrane, we found the neurons are also acting as thermoscell that convert their metabolic heat into electric charges through a series of thermo-electrochemical processes by involving the found transmembrane temperature difference and Seebeck effect. The measured transmembrane potential can be plausibly explained by accumulations of the potentials of the generated nerve impulses which are defined as electric charges that have electric potential. The neuron's power is directly calculated as the product of the generated membrane's potential times the measured rate of entropy growth through axons by Ammeters. Such proper understanding of the generated neuron's power improves a traditional hypothesis of ATP synthesis that explains generation of electrochemical signals, ignores the flow of nerve impulses as electric energy, and violates laws of thermodynamics.

Keywords: Nerve Impulses, Electric Charges, Electromagnetic waves, Brain Waves, Thermocell, Transmembrane Seebeck Effect, Neuron Power

Introduction

According to the introduction of the Hodgkin-Huxley model of action potential in the 1950s, the nerve impulse generation and propagation are often thought of as solely electrical events [1]. To this day, this model forms the physiological foundation for a broad area of neuroscientific research [2]. However, the physicians or neuroscientists working with electroencephalogram EEG found, according to this model, confusion in finding the theory that explains in an accessible way the physics of such bioelectrical activities [3]. Similarly, such an original model cannot find a plausible explanation of generation of action potential in the neuron's membrane or the source of the measured brain waves [4].

Additionally, this model finds difficult understanding of the high metabolic load of the human brain, which is just 2% of the body's weight, while it consumes 20% of the body's metabolic heat and 10 times more consumption per gram than any muscle [5, 6].

Accordingly, the Hodgkin-Huxley model was developed by various modifications to find plausible explanations of the discussed problems in addition to measurements of peripheral conduction of the nerve impulses [7].

As an approach, the volume conductor (VC) model was introduced to explain the measured magnetic field produced by propagating nerve impulses by the transmembrane action potential up to peripheries of the neurites [8]. The volume conductor is defined as any neural fiber, as axons, which allows the flow of nerve impulses or action potentials by electric conduction. As proof of validity of the introduced VC model, the shape of the transmembrane potential was successfully calculated from the measured magnetic field. Results of the field's measurements determined the internal resistance per unit length of the axon and the value of its internal conductivity. However, the measured electric conductivity proves the ability of the neural fibers to conduct electricity or nerve impulses in the form of electric charges. Such a conclusion violates the classical definition of the electric charges as electrons that cannot flow through organic materials. So, we introduced in this study an innovative definition of the electric charges as electromagnetic (EM) waves that have an electric potential [9,10]. Such definition of the electric charge can find a plausible explanation of the flow of the nerve impulses through the volume conductors as electric charges or electric signals. The classical definition of the flow of nerve impulses as slow ionic interaction contradicts the measured rapid conduction of the nerve impulses through neural fibers as electric signals [11].

Additionally, the measured magnetic field of the axons, as volume conductors, by induction is evidence of the propagation of the nerve impulses as electric charges through neural fibers according to Faraday's principles [12, 13]. However, literature of neurosciences define the motion of the action potential as generators of the induced magnetic field in the volume conductors, while the motion of potentials cannot induce a magnetic field according to the laws of induction [14]. So, we introduced in our study a new definition of nerve impulses as the innovatively defined electric charges, i.e., EM waves that have an electric potential [15]. The definition of the nerve impulses as electric charges in the form of EM waves, also finds plausible explanations of the measured rapid conduction of the nerve impulses and the measured induced magnetic field through the volume conductors [16]. The word "Potential" is used in the scientific literature as a potential of energy, as the potential of electric energy or of the thermal energy, and it is proportional to the concentration of such energy and has the unit "Volt" [17].

The traditionally used definition of the nerve impulses in the neuroscientific literature as action potential represents a source of redundancy as the flow of nerve impulses is an electrical signal or electric energy which is measured by "Joule" [18]. While the action potential is the potential of the nerve impulses which is measured by "Volt." So, the innovative definition of the electric charge distinguished the "action potential" as the electric potential of flowing nerve impulses or potential of the neural signals and it is not a potential of nothing.

Neuroscientists recognized the neurons as generators of EM waves, but they failed to find the method of its generation because they defined the nerve impulse as an action potential and the electric charges as electrons [19]. So, modifying the VC model by a new definition of the nerve impulses, and an innovative definition of the electric charges as electrified EM waves, as well as recognizing a transmembrane Seebeck effect of neurons, we found the neurons have pillars to operate as the thermos-cells that convert the metabolic heat into electric charges, or nerve impulses [20]. Defining the function of a neuron as a thermo-cell, we can find a plausible explanation of the high consumption of the brain's metabolic heat. Additionally, the measured brain waves can be plausibly explained as diffusion of the generated nerve impulses as EM waves from the neurons through the neural fibers. Recognizing the function of the neurons as generator of the potential and energy of the nerve impulses, modifies the traditional hypothesis of ATP synthesis that assumes generation of flowing potential or impulses as electrochemical signals of unknown resources [21].

An innovative definition of electric charges

The classical definition of the electric charges as electrons that have a theoretical drift speed in the order of millimeters per second in good conductors contradicts the measured speed of electric charges in such conductors or the wireless transmission of electric power which approaches the speed of light [22, 23].

Additionally, its modern definition as a property is not a logical definition as the property cannot flow and its flow cannot be measured by Ammeters [24].

Accordingly, our study introduces an innovative definition of the electric charges as flow of energy in the form of electromagnetic waves that have electric potential [25, 26]. Such definition found plausible explanations of different phenomena in the field of electromagnetism and solved redundancies in this field such as the duality confusion and achieving high efficiencies of modern photovoltaic cells that exceed the limits determined by Shockley and Queasier analysis [27, 28]. The following equations represent the mathematical formulation of such innovative nature of the flow of the electric charges as EM waves of electric potentials which were found as solutions of the Maxwell's EM wave equations [29, 30]

$$E = E0 + E_1 \cos(\omega s) \qquad (1)$$

$$H = H_1 \cos(\omega s) \qquad (2)$$

Where "E" and "H" represent the electric and magnetic components of the wave in volts, "E0" is the electric potential of the electric charge, "E1" and "H1" represent the amplitudes of the EM waves in Volts, "ω" represents the

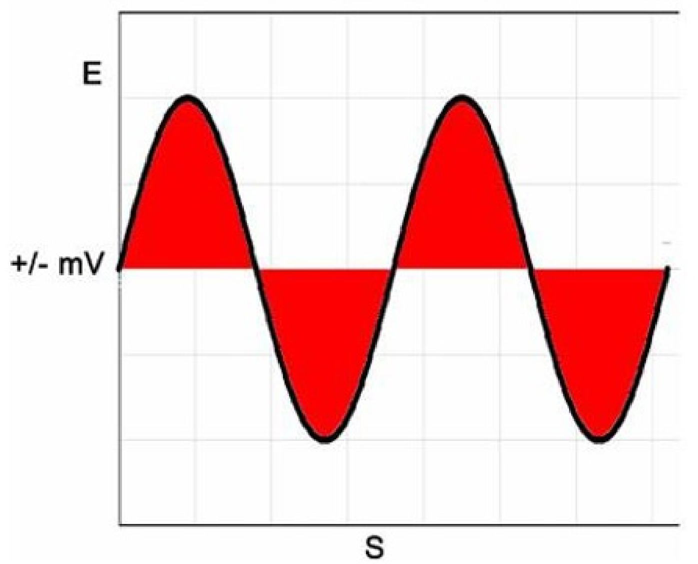

Figure 1. Representation of flow of electric charges as energy of positive or negative electric potential in E-S coordinates [32]

Figure 1. represents an "E-s" diagram of an electric charge defined as a component of an EM wave according to Eq. 1 whose electric potential is "E0" [32]. Fig. 2 represents an "E-s" plot of a stimulating charge from an electric stimulator where the ordinate represents the flowing entropy "s Joule/Volt" determined by the

product of the Ammeter's reading in "Watt/Volt" times the measured time of injection in the body of the patient in seconds [33].

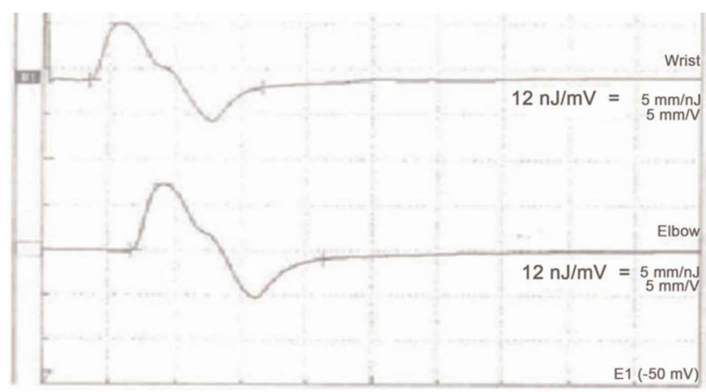

Figure 2. A machine record of a stimulating electric charge injected inside the wrist (the upper wave) and the Elbow through neural system of patient. The ordinate shows the potential of the electric charge in mV and abscissa shows the entropy growth during the flow as the product of the Ammeter's reading times the time of flow through the Ammeter in nJ/mv [33].

Reviewing the representation of the electric charge as a theoretical solution of Maxwell's wave equations in Figure 1 and the measured plot of the electric charge from a stimulation device in Figure 2, we found both figures are similar. Such similar identity represents proof of the nature of the injected electric charge as an EM wave found by a theoretical solution of Maxwell's wave equations. So, the electric charge is an EM wave whose electric component has an electric potential "E0" and its electric energy is the area enclosed by the E-s plot in Figure 1 or Figure 2 according to the following equation [32]:

$Q_{elect} = \int E \, dS_{elect}$ (3)

A new definition of nerve impulses

Electrical signaling is found to be a cardinal feature of the nervous system and endows it with the capability of quickly reacting to changes in the environment [34]. However, neuroscientists describe the flow of nerve impulses as flow of action potentials that are slowly drifted by difference of concentrations of ions along the neural fibers [35]. The classical definition of electric charges as electrons which cannot flow through organic neural fibers abandon the proper definition of the nerve impulses as electric charges. However, the flow of the nerve impulses is defined as electric signals whose measured velocity is higher than the traditionally considered ions interactions [36]. Such improper definition of the electric charges as electrons also disables researchers to find the method of generation of brain waves [37].

According to the Hodgkin-Huxley model, the generation and propagation of the nerve impulse are solely electrical events [38]. This model was modified by the volume conductor (VC) model which considers the neural axon as a volume conductor that conducts electricity in the form of nerve impulses, or wrongly as action potentials [39]. Bradely and others used this model to calculate and measure the generated magnetic field in a single nerve axon and found the predicted shape of the magnetic field from a measured transmembrane potential is identical to the measured one [40]. They determined the internal resistance per unit length of the axon "R_i= 19.3 ± 1.9 kΩ/ mm, implying a value for the internal conductivity of 0.44 ± 0.033 mm/ kΩ. The found measurements of the electric conductivity of the neural fibers and the magnetic field generated by the flowing nerve impulses prove the truth of the new definition of the propagating nerve impulses as electric charges that can flow through such fibers and induce the measured magnetic field according to Faraday's principles [41]. The recorded EEG in Fig. 3 of diffusion of the brain nerve impulses as EM waves through neural fibers are identical to the mathematical solution of Maxwell's wave equations in Fig. 1 represents propagation of the nerve impulses as a generated EM wave [42]. Additionally, the recorded membrane potential in Fig. 4 is also identical to the graphical representation of EM wave of Eqn. 1 as plotted in Fig. 1 that indicates the following measured data [43]:

The wave potential: E0 = −60 μ V,

Amplitude of the wave: E_1 = 10 μ V,

Frequency of the wave = 5 Hz.

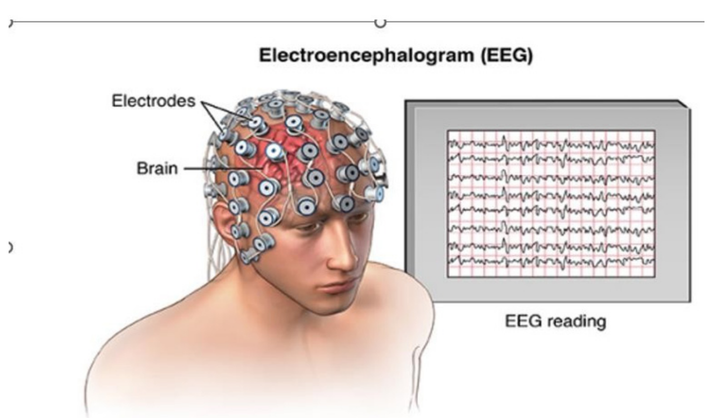

Figure 3. A Scheme of recording the brain's waves [42].

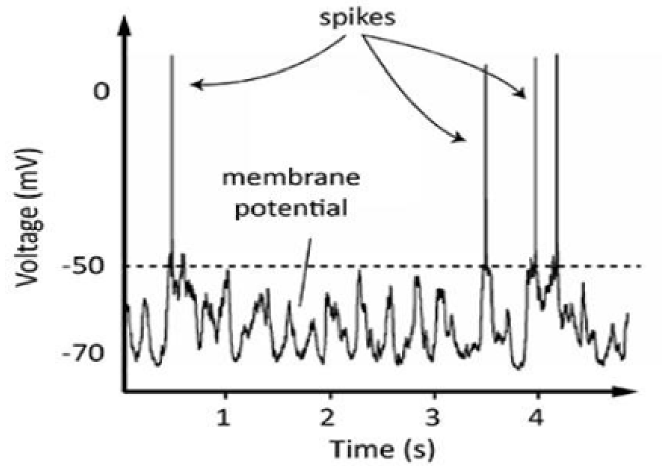

Figure 4. An example of brain waves from an actual neuron in the mouse's cortex [43].

So, the measured transmembrane potential can be defined as the potential of generated nerve impulses in the neurons. Hence, the recorded brain waves of the human skulls as shown in Fig. 3, may represent the diffusion of generated nerve impulses in the brain neurons according to the following diffusion equation [44]:

$$\frac{\partial^2 E_{imp}}{\partial x^2} + \frac{\partial^2 E_{imp}}{\partial y^2} + \frac{\partial^2 E_{imp}}{\partial z^2} = \frac{\dot{s}}{\alpha_{elect}} \frac{\partial E_{imp}}{\partial S} \quad (4)$$

Where "Eimp" is the potential of the measured propagating nerve impulses in Volt, "α_{elect} " is the diffusivity of the neural fibers, "S" is the entropy of the fibers, and "s" is the measured rate of entropy flow by an Ammeter [46].

The potential of the propagating nerve impulses was found as a solution of Eqn. (4) as follows [45]:

$$E(x, \tau) = E_{membrane} - E_0 e^{-x/\delta} \cos(\omega\tau + x/\delta) \quad (5)$$

Where:

$$\delta = \sqrt{\frac{2\alpha_{imp}}{\omega}} \quad (6)$$

So, the new definition of the nerve impulse, as electric charges that have the nature of EM waves, successfully predicts the brain waves according to Eqn. (5), as a solution of the diffusion equation of the propagating nerve impulses generated in the neurons.

The transmembrane Potential

A typical human neuron can be mainly examined in three main sections as the dendrites, axon, and soma, Fig. (5) [46]. The cell body of the neuron, the soma, is about 20 μm in diameter and contains most of the organelles such as the nucleus, mitochondria, endoplasmic reticulum, ribosomes, and the membrane of the cell. At the cell body, the cell produces metabolic heat which is the source of energy in the neural system.

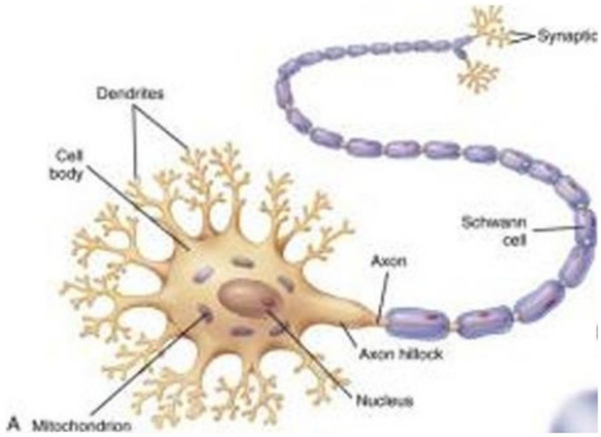

Figure 5. Structure of a neuron [46].

At the sides of the membrane of the nerve cell, there is Sodium as a principle extracellular cation and there is Potassium as the principle intracellular cation, as

shown in Figure. (6) [49]. From tables of the Seebeck coefficients, we find the Seebeck coefficient of Potassium is – 9 μ V / deg, while the Seebeck coefficient of Sodium is - 2 μ V / deg [50]. According to such difference of the Seebeck coefficients on the sides of the membrane, there exist a transmembrane Seebeck effect "Se" which is defined as the difference between the Seebeck coefficients on the sides of the membrane as follows [50]:

$$S_e = S_{Potassium} - S_{sodium} =: -9 - (-2) = -7\ \mu V / deg \quad (7)$$

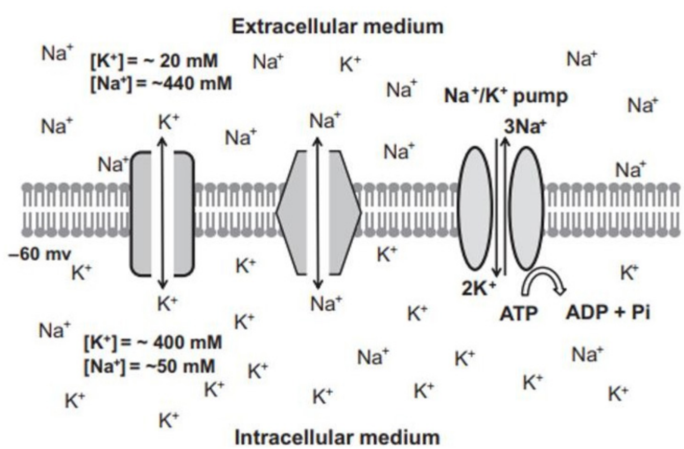

Figure 6. Distribution of sodium and potassium ions across the phospholipid bilayer of a typical cell membrane [49].

The recognized transmembrane Seebeck effect encompass the conversion of the temperature gradient (Δ T) of the neuron's input metabolic heat into electrical potential (Eoutput) of the output nerve impulses, or electric charges, as done by the thermocells where such conversion is performed by thermos–electrochemical processes [51]. According to the laws of thermoelectricity, the transmembrane

electric potential, "$E_{n.output}$," of the generated nerve impulses, that cross the membrane, is proportional to the thermal potential of the metabolic heat inside the neurons "ΔT, and the transmembrane Seebeck coefficient according to following Seebeck equation [52]:

$$E_{n.output} = S_e * \Delta T \quad \frac{Volt}{nerve\ impulse} \quad (7)$$

The measured temperature difference between the intercellular medium and the extracellular medium of a neuron due to evolution of the metabolic heat inside the neurons is 1.6 degrees [53]. According to Eqn. (7), it is possible to calculate the electric potential of the converted energy that crosses the neuron's membrane as electric charges, or nerve impulses, as follows:

$$En.output = -7 * 1.6 = -11.2\ \mu V \quad (8)$$

According to neuroscientific literature, the measured transmembrane potential is – 60 m. Volt [54]. So, it is possible to count the number of permanent nerve impulses whose accumulated electric potential produces the total transmembrane potential as follows [55]:

$$E_{membrane} = \sum_0^m E_{n.output} = m * Se * \Delta T \quad (9)$$

Where "m" is the number of generated nerve impulses in every neuron which can produce the measured transmembrane potential. Substituting the previous data in Eqn. (9), it is possible to estimate the value of the number "m" as follows:

$$m = 60\ mVolts/1.6\ deg * 7\ \mu V / deg = 5360\ charges\ (or\ nerve\ impulses) \quad (10)$$

The result found in Eqn. (10) indicates the frequency of the generated nerve impulses in the neurons, each in the form of Fig. 1or 2, that leads to the permanent accumulation of the measured membrane potential of 60 mVolt [56].

The Neuron's Electric Power

According to Eqn. 10, the neuron generates the transmembrane electric potential, called as the action potential, by accumulation of the potentials of the generated

electric charges on the neuron's membrane. Such generated potential drives the flow of the generated nerve impulses through the neuron's axon shown in Fig. 5, as electric charges, or nerve impulses by analogy of driving of thermal radiation by its thermal potential [57] . Following the VC model, it was possible to find the Ammeter's reading of the flow through the neuron's axon as 6 $\frac{Watt}{Volt}$ Watt [58].
Volt
Such Ammeter's readings measure the rate of growth of entropy, as a property of electric conductors, through the axon [59]. Hence, it is possible to calculate the neuron's power as the product of its generated transmembrane potential in Volts times the measured entropy growth through the axons by an Ammeter in $\frac{Watt}{Volt}$

follows:

$$W_{neuron} = Ammeter's\ reading * Membrane'spotential = 6\ nano\ \frac{Watt}{Volt} * 60\ mV = 360 * 10^{-15} Watt. \quad (11).$$

Accordingly, the number of neurons in the brain is found by dividing the estimated brain power of 20 Watt by the power of a neuron as follows:

$$number\ of\ brain's\ neurons = {}^{20}/_{360} * 10^{-15} \cong 55.5 * 10^{12}\ neurons \quad (12)$$

For half a century, the human brain was believed to contain less than 100 billion neurons and one trillion glial cells, with a glia: neuron ratio of about 10:1 [60]. However, such counting did not take into consideration the neuron's generation power and the brain's power. It is the first time to depend on measured neuron's power that depends on measurement data and on the estimated brain's power [61].

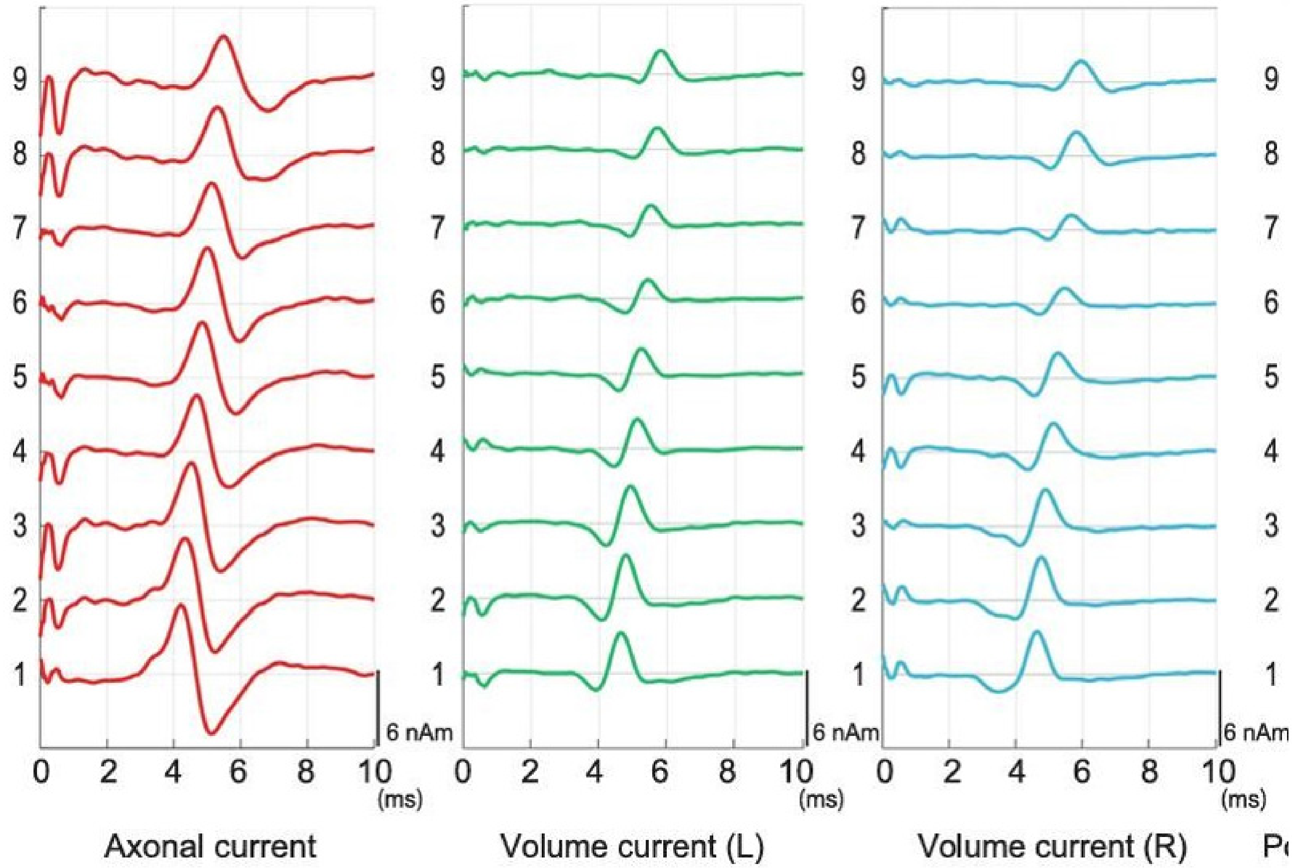

Figure 7. The waveform of the current in the axonal direction (red plots), in the perpendicular direction to Left of the axon direction (L: the green plot), and in the perpendicular direction to Right (R: the red plot) of the axon direction [58].

Confirming the Introduced Understanding of the Neuron's as Power Generators

According to the traditional definition of the electric current as flow of electrons, neuroscientists abandon the definition of the flow of nerve impulses as electric charges while such flow is observed as electric signals. So, it is introduced the traditional hypothesis "Adenosine triphosphate (ATP) synthesis" to define a source of biological energy that triggers the muscle interactions by electric potentials [62]. However,

However, such hypothesis was found to violate laws of thermodynamics as the action potential, which is defined as an effect, cannot initiate a release of triggering energy [63]. So, the followed approach in this study that defines the neurons as generators of the required electric power and potential of the nerve impulses can plausibly explain the source of the required triggering energy by conduction of the electric charges along the axons [64].

Conclusions

By modifying the volume conducting the (VC) model through introducing a new definition of the nerve impulses as electric charges, which were innovatively defined as electromagnetic waves that have an electric potential, it was possible to find plausible explanations of mysterious questions in the field of neurosciences as follows:

1. The distribution of the Sodium and Potassium ions which have different Seebeck coefficients on the two sides of the cell's membrane creates a transmembrane Seebeck effect that converts the thermal potential of the neuron's metabolic heat into electric, or action, potential of generated nerve impulses that crosses the neuron's membrane.
2. The accumulation of the converted potentials of the generated nerve impulses on of the neuron's membrane creates the measured transmembrane action potential.
3. The high brain's consumption of the body's metabolic heat is because of its conversion into electric power in the brain's neurons to perform the brain activities in the neural peripheries..
4. This article deletes redundancies in the neurosciences that defines the action potential as a nerve impulse, as the action potential is measured by Volt and the nerve impulse is electric energy which should be measured by Joule.
5. The brain waves are plausibly explained as diffusion of the neuron's generated nerve impulses. whose nature is EM waves, through the neural conductors.
6. The Ammeters measure the entropy of the neural conductors as a neurodiagnostic property of the neural fibers that determine their capacity to allow flow a certain rate of flow of nerve impulses by a unit electric potential in addition to the entropy's definition as a mathematical tool for quantification of the neural functions.
7. According to the estimated brain's power of 20 Watt and measured neuron's power as the product of measured transmembrane potential times current through the axon; we have estimated the number of neurons in the human brain as $55.5 * 10^{12}$ neurons.

Declarations

Competing interests

The authors declare that has no competing interests.

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