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A Proper Definition of Neuromodulation as Superposition of Two Electric Currents

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Abstract

While neuromodulation represents a successful technique for therapy of critical mental and health cases, there is not a universally accepted mechanism of how its applying may change the electrical activity of neurons and influence the flow of nerve impulses through axons. As an approach to find plausible explanation of the measured impacts of such technique, we followed an innovative definition of the nerve impulses as electric charges since the electric charges were recently defined as electromagnetic waves that have electric potential. Such approach succeeded in finding plausible explanation of how the flow of nerve impulses from neurons through the neural fibers was measured as electric signals associated by recorded moving potentials which was traditionally called "action potential." Such approach also led to define the neurons as thermo-cells that convert their metabolic heat into electric nerve impulses and the axons as transmission lines of such impulses. In the present study, we extend the application of this approach to recognize the neuromodulation as superposition of the modulating electric current and the current of flowing nerve impulses through axons. Such conclusion succeeds to plausibly explain the recorded impacts of neuromodulation on activation or deactivation of generation of nerve impulses and on strengthening or retarding the flows of nerve impulses through the axons according to the polarity of the modulating current. Understanding the current density as a property that depends on the entropy growth rate through the neural conductors, it was possible to determine the value of a proper threshold power of the injected or induced current that may excite the neural systems.

Keywords: Neuromodulation, Stimulation, Nerve Impulses, Electromagnetic waves, Transmission lines, Neuron power, Entropy, Threshold power

Introduction

Neuromodulation represents now an essential technique for therapy of critical problems in mental and physical health by delivering precise stimulation to specific areas in the body to modify the generation and flowing of the nerve impulses through the neural system [1]. However, due to the confusions of proper definitions of the nerve impulses as electric charges and the neurons as generators of such impulses, neuroscientists fail to find plausible and systematic explanations of how external electric and magnetic fields (EMFs) may cause such modification [2]. The current explanations point to a complex interaction of direct biophysical effects and downstream cellular changes, but a single, universally accepted mechanism is lacking [3]. However, the wrong definition of the electric charges as electrons which, according to traditional definitions, cannot flow through neural tissues misled the neuroscientists to achieve plausible explanations of generation of the action potential and the processes of neuromodulation [4]. However, the nowadays wireless transmission of electric power violates this definition [5]. We explain in this article how an analogy between the laws that characterize the flow of heat and the flow of electric charges led to defining the electric flux, like the heat flux, is a flow of electromagnetic waves that have an electric potential [6]. Such recognition was experimentally verified by one of Faraday's experiments that converted the light, as flow electromagnetic waves, into flowing electric current by subjecting such light to an electric field [7]. We review in this study the foundations of this definition and how this approach led to an innovative definition of the nerve impulse as electric charges. Such definition found a plausible explanation of measuring the flow of nerve impulses through axons as electric signals. Additionally, the new definition corrects a traditional definition of the nerve impulses as action potentials which violates the proper understanding of the nerve impulses as energy and of the action potentials as a driver of such energy [8, 9]. As the flow of nerve impulses through neural fibers is measured as electric signals, we will review in our study how the neurons are recognized as thermo-cells which have a transmembrane Seebeck effect to convert their metabolic heat into electric charges or electric nerve impulses by exchanging the neuron's thermal potential to impulse's electric potential [11].

According to Faraday's law of induction, the flow of magnetic flux induces electric current, and the flow of electric current creates magnetic flux which means both fluxes have analogical natures [12]. Hence, the nature of the magnetic flux was also defined as EM waves whose magnetic potential can be converted by induction into electric potential [13]. We will introduce in our study a modified form of simple wave equations, derived from Maxwell's wave equation, that represented the flow of electric current and magnetic flux as EM waves of corresponding potentials [14]. Such equations were modified by replacing the time in these equations by entropy, as a property of the neural fibers, whose growth is associated by the flow of electric current or magnetic flux [15]. According to thermodynamical principles, such entropy growth leads to dissipation of heat through the neural fibers and is determined in our study to count the thermal effects of the threshold electric power.

So, an objective of the present study is to analyze the impact of the reviewed innovative definitions of the nerve impulses, action potential, and neuron's power on a proper understanding of neuromodulation by electric or magnetic stimulation. The main approach to find plausible explanations of the neuromodulation, as will be discussed, depends on realizing the similarity of the natures of the nerve impulses and of the deploying direct or induced electric fluxes. As will be seen, such approach leads to finding convenient mechanisms of neuromodulation by electric or magnetic energies.

Natures of the Electric Charges and Magnetic Flux

According to an analogy between the laws that characterize the mechanisms of transport of thermal, electric and magnetic energies, and the mutual conversions between the three fluxes, their flows were defined as flow of electromagnetic (EM) waves [16]. The thermal radiation, or light, is defined as flow of EM waves that have thermal potential and associated by growth of entropy, the flows of electric charges and magnetic flux were also defined as flow of EM waves that have electric or magnetic potential and are also associated by growth of entropy [17]. So, the following simple wave equations were derived from Maxwell' wave equations to describe the light or thermal radiation as electromagnetic waves of electric (E) and magnetic (H) fields that propagate at perpendicular planes [17]:

$$\nabla^2 E = \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} \quad (1A)$$

$$\nabla^2 H = \frac{1}{c^2}\frac{\partial^2 H}{\partial t^2} \quad (1B)$$

where ∇^2 is the Laplacian operator, c is the speed of light = 3×106 m/s. As discussed, the time coordinate of such wave was replaced by entropy "s," as the entropy is an energy coordinate which depends mainly on time and represents the associated growth of entropy of the conductors by the flowing wave energy. Such replacement casts the previous simple wave equations into an energy frame of reference as follows [16].

$$\nabla^2 E = \frac{1}{c^2}\frac{\partial^2 E}{\partial s^2} \quad (2A)$$

$$\nabla^2 H = \frac{1}{c^2}\frac{\partial^2 H}{\partial s^2} \quad (2\ B)$$

According to one of Faraday's experiments where he passed light waves through an electric field and found such electrified waves have the characteristics of electric current that produces a magnetic field [18]. Such experiment proves the flow of electric energy is a flow of electrified EM waves or EM waves that gained an electric potential [19]. Hence, it was possible to introduce the following mathematical representation of the flow of electric charges as flow of EM waves which have positive or negative electric potential, ± Δ E, as a special solution of the equations 2 A and 2 B whose initial conditions are as follows [19]:

$$E_{at\ t\ or\ s=0} = E_0 \quad (3A)$$

$$H_{at\ t\ or\ s=0} = 0 \quad (3B)$$

So, the solution is as follows:

$$E = E_0 + A_e \cos \omega s \quad (4A)$$

$$H = A_m \cos \omega s \quad (4B)$$

Where ω=2 π f , "f" is the frequency of th wave.

Figure 1 represents the flow of an electric charge as an EM wave as described by the equations 4A and 4 B, the electric wave oscillates around a negative electric potential "- E_0 ." in the E-s energy frame and the magnetic wave oscillates around a "zero" magnetic potential in the H – s energy frame [24]. Similarly, the positive charge can be represented by EM wave whose electric wave has a positive potential [20].

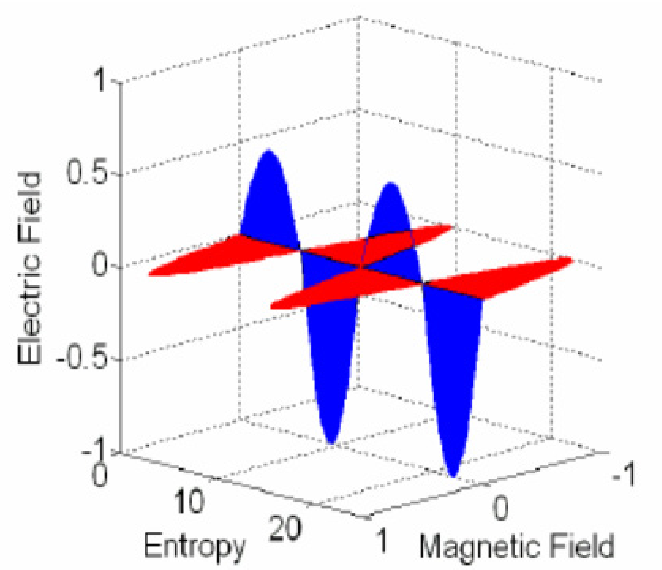

Figure. 1. Flow of negative electric charges as flow of electromagnetic waves of –ve potential where the electric energy in the E-s plane is oscillating around a negative potential [24].

According to previous studies, entropy was defined as a fundamental physical property or state function of materials, representing their inherent disorder, randomness, or energy dispersal [21]. So, the transport of thermal, electric, or magnetic energies through any material is defined to be associated by the growth of entropy of such material [22]. The rate of growth of entropy of a material, denoted as "*S*," which is associated by the flow of thermal, electric, or magnetic energy, "*Q*" watt through such material, is determined as follows [22]:

$$\dot{S} = \frac{\dot{Q}}{E}\ \frac{Watt}{Volt} \quad (5)$$

Where "E" in Volt is the driving potential of each energy transportation, which is found to be proportional to the volume concentration of the transported energy [23].

According to Eq. (5), the unit of the rate of growth of the associated entropy is "$watt/_{Volt}$". Such unit is the same as the unit of the Ammeter's readings. So, the Ammeter was defined as a device that measures the rate of growth of entropy in conductors since the flow of electric current is associated by growth of entropy which has the same unit of the Ammeter's readings [24]. The definition of Ammeters as devices that measure rate of associated growth of entropy corrects the definition of the Ammeters as devices that measure the rate of flow of electric charges by a confusing unit, the Ampere, which depends on a wrong definition of the electric charges as electrons [25]. Defining the readings of Ammeters as rate of flow of electric energy should have the units of power in "Watt" if the electron is measured, as energy, by the Joule. The associated growth rate of entropy through any material depends on the properties of materials and the rate of growth of entropy per unit area of any material which was traditionally called "the material's current density" is also defined as a property [26]. As examples, the measured current densities in Copper and Aluminum are 1.6 "$watt/_{Volt*mm2}$", and 1.0 $watt/_{Volt*mm2}$" respectively [27].

According to the definition of entropy as a measure of randomness and disorder in a material, its growth which is associated by the flow of any energy, leads to the loss of such energy and its conversion into heat that is dissipated through the conductor. Such heat loss is expressed as the measured growth of entropy by Ammeters "S" times the potential drop across the conductor "ΔE" as follows:

$$\dot{Q}_{thermal} = \dot{S} * \Delta E = \dot{s} * A * \Delta E \quad (6)$$

Where "s" is the rate of growth of entropy per unit area of material, and "A" is the cross-sectional area of such conductor [22].

An innovative definition of nerve impulses as electric charges and the axons as Transmission Lines of the nerve impulses

A volume conductor (VC) model was introduced in neurosciences to explain the measured magnetic field produced by propagating nerve impulses through neural fibers [28]. The volume conductor is defined as any neural fiber, as axons, which allows the flow of nerve impulses which was defined wrongly and traditionally as "action potentials." According to the results of field measurements, the internal resistance per unit length of an axon was found as 20 k Ω/ mm [28]. Such measurement results prove the validity of the introduced VC model and the ability of neural fibers to conduct electric charges. According to the definition of electric charges as flow of EM waves that have electric potential, and the definition of the neural fibers as conductors of electric charges, the nerve impulses were defined as electric charges that flow through the axons, and their potential was recognized as the traditionally called electric potential [29]. As a conclusion, such moving velocity of an electric potential through axons, and recorded by highly sensitive electrophysiological techniques, was wrongly defined as a moving alone potential and it is a potential of flowing energy [30]. Defining the recorded moving potential as a moving alone potential that doesn't belong to any. energy ignores a physical concept that the potential is a driver of any energy, as it is proportional to the volumetric concentration of such energy [31]. So, the potential of the electric impulses is maximum at the neuron's membrane and is decreasing along the axon to overcome the axon's electric resistance. This explains the generation of action potential by the transmembrane Seebeck effect and explains the measured decaying potential of long-distance electrical signals through the neural fibers [32]. So, the axons were recently defined as electric conductors or transmission lines which conduct the nerve impulses as electric charges in the form of electromagnetic waves that have an electric potential defined by Equations 3 A and 4 A [33].

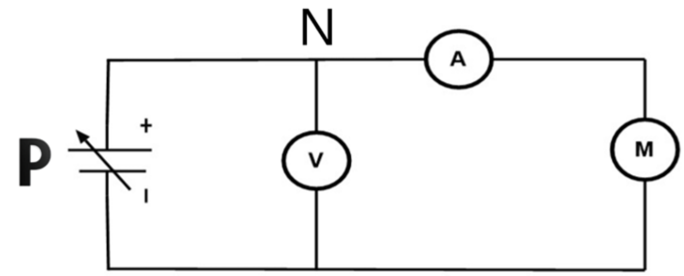

Figure. 2. Layout of a test rig for measuring the electric power flow through a connected sciatic nerve of a chicken PN, from a d/c power supply P to an electric motor M, through an Ammeter A [33].

The proof of this definition was done by inserting a sciatic nerve of a chicken in the electric circuit shown in Fig. 2 [33]. The circuit connects a Power supply "P" to the node "N" by the sciatic nerve "P-N," and a connected Ammeter "A." According to the proper understanding of the function of the Ammeters as devices that measures the rate of growth of entropy through the conductors that is associated by the flow of electric energy in Watt/Volt. So, the introduced Ammeter "A" in the drawn circuit measured the rate of growth of entropy through the sciatic nerve during transmission of electric power from the power supply for different lengths of nerve. The estimated current density, or the rate of growth of entropy per unit are of the axons has the same measured value for different lengths of the sciatic nerve [33]. Such results prove the rate of growth of entropy per unit area of the axon, as electric conductor, is a property of any material [34].

As measurement results of the previous experiment, the electric resistance per unit length of the sciatic nerve is found as 12 k Ω/ mm which is in the same order of the found result for a different diameter by Roth and Wiskow [28]. So, this circuit finds an experimental proof of the flow of nerve impulses as electric signals and violates the traditional definition of the flowing nerve impulses as flow of action potentials or ionic reactions (primarily sodium and potassium).

Generation of The Nerve Impulses in the Neurons

At the cell body of a neuron, as shown in Figure. (3), we find such cell produces metabolic heat which is the source of energy in the neural system [35].

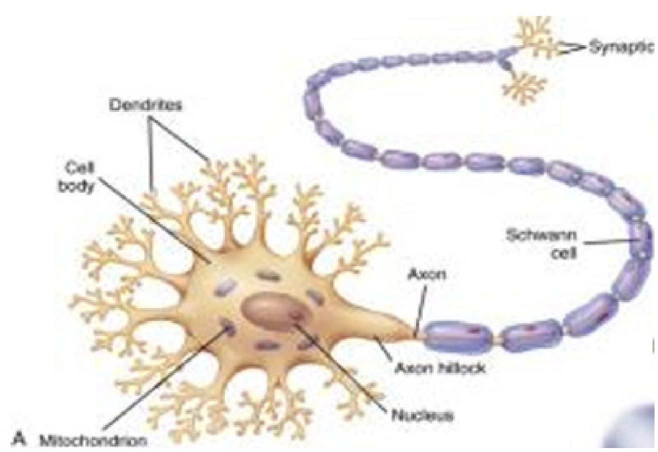

Figure 3. Structure of a neuron [35].

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. (4) [36]. 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 [11]. According to such difference of the Seebeck coefficients on the sides of the membrane, we conclude existence of a "transmembrane Seebeck effect "S_e= - 9 – (- 2) = - 7 μ V / deg." So, the thermal potential of the neuron's metabolic heat "ΔT" can be converted into electric potential " Δ E" when some of the of the neuron's metabolic heat crossed its membrane by such transmembrane Seebeck effect. Such performance is like the performance of thermo-cells which convert heat by thermos–electrochemical processes into electric charges when converting the thermal potential of the heat into electrical potential by a corresponding Seebeck effect [37]. According to such principles, a potential difference "ΔE_{dipole}" may be created by each dipole, as a neural fiber, that connects a Potassium ion to a Sodium ion on the sides of the membrane, to convert the transmembrane temperature difference, measured as 1.6 degrees, into electric potential determined as follows [38]:

$$\Delta E_{dipole} = S_e * \Delta T -= 7 * 1.6 = -11.2\ \mu\text{V} \qquad (7)$$

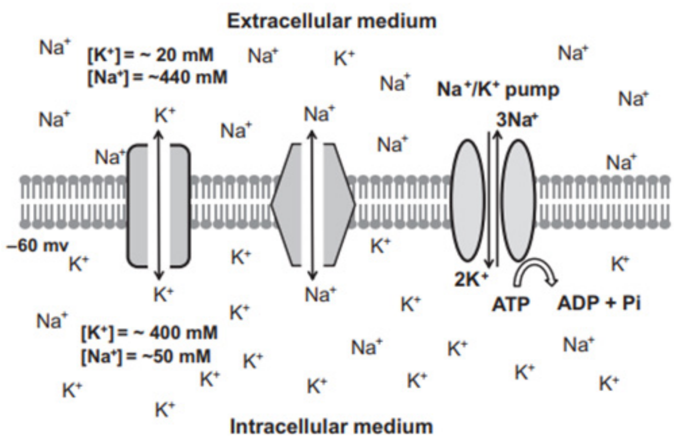

Figure. 4. Distribution of sodium and potassium ions across the phospholipid bilayer of a typical cell membrane [36].

According to Fig. 5, the measured transmembrane potential is – 60 m. Volt [39]. So, it was possible to count the number of transmembrane neural dipoles "m" whose accumulated electric potential produces this total transmembrane potential as follows:

$$E_{membrane} = m * \Delta E_{dipole} = m * -11.2\ \mu\text{V} = -60\ \text{m V} \qquad (8)$$

So,

m = 60 mVolts⁄1.6 deg* 7 μ V / deg =5360 diploles (9)

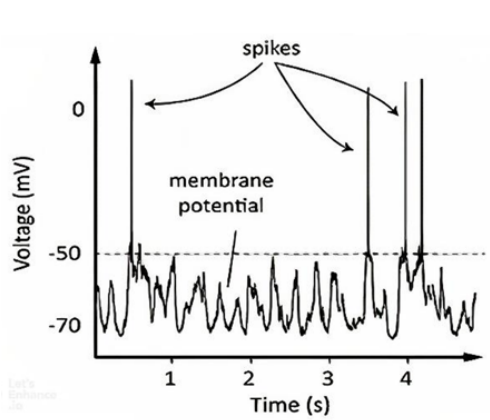

Figure. 5: Neuron's Membrane Potential [39].

However, such number of contributing dipoles in generating the measured membrane's potential may depend on the brain's activity in every time [40]. Eqn. (7) indicates how such potential is generated according to summation of accumulating the potentials of the neural fibers connecting the Sodium and Potassium ions on the sides of the neurons transmembrane.

Stimulation of the neural system by external electric currents

The use of electrical charges to stimulate the neural system began with pioneering scientific experiments in the late 18th century. Figure 6. shows a record of an injected electric charge used for stimulation of the neural system of a patient in the form of an oscillating wave about an axis of positive potential ordinate [41]. So, this is defined according to the previous review as a positive charge. The abscissa records the growth of entropy through the neural fibers during the flow of the injected electric charge in n. joule/volt, found as the productor of the Ammeter's readings in Watt/Volt times the injection time in seconds. The ordinate records the variation of the potential of the injected charge during the process in Volts. Such an experimental record, as represented in Fig. 6, is identical to a representation of the flow of an electric wave, found as analytical solution of the modified Maxwell's equations, in Figure. 1.

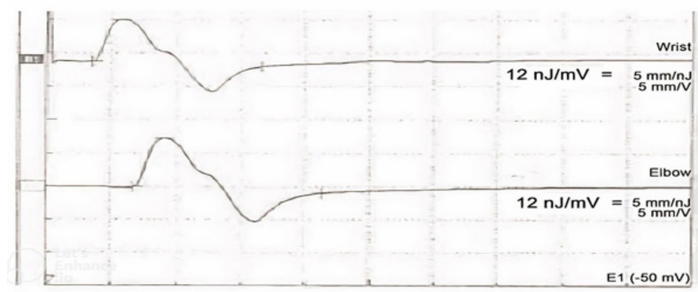

Figure. 6. A machine record of a stimulating electric charge injected inside the wrist (the upper wave) and the Elbow through neural system of patient. The ordinate shows the potential of the electric charge in mV and abscissa shows the entropy growth during the flow [41].

Such identity proves the truth of considering the flow of electric charges, electric current, as flow or EM waves that have electric potential and associated by growth of entropy. According to the data on Fig, 6, it is possible to read the recorded growth of entropy during one wave = Δ S = 3 nano-Joule/volt and the recorded time duration of the pulse = 0.2 milli Second. Such data is determined by an Ammeter's reading which expresses the rate of growth of entropy through the neural system, traditionally called the current, which can be estimated as follows:

$$\dot{S} = \frac{\nabla S}{\tau} = \frac{3*10^{-9}}{0.2*10^{-3}} = 15\ m.\frac{Watt}{Volt} = 15\ m.{}^{Watt}/_{Volt} \qquad (9)$$

However, such stimulation can be also achieved by magnetic flux which induces, according to Faraday's law, a similar electric current [42].

Proper understanding of the Neuromodulation by deploying external injected or induced electric current

According to the previously reviewed studies, we have innovative definitions of the nerve impulses as electric charges and of the neurons as generators of such nerve impulses by conversion of their metabolic heat into electric nerve impulses. So, the introduced review shows similarity of the natures of the external injected or induced electric currents and of the generated or flowing nerve impulses. Accordingly, neuromodulation can be plausibly explained as interference between the external electric current and the generated flow of nerve impulses according to the principles of superposition [43]. Such concluded neuromodulation by superposition of electric currents is the key for proper understanding of the mechanism of neuromodulation and corrects a traditionally explained mechanism by polarization or depolarization which lacked a plausible explanation [[43]. The stimulation measurements show if the injected electric current has a negative potential (cathode), this charge tends to excite the flow of nerve impulses [44]. According to the concluded mechanism of superposition of electric currents, this measured excitation can be plausibly explained because of summation of two negative potentials of the interfering currents, the potential of the generated nerve impulses "E_g" and the potential of the injected or induced electric charges "E_i". So, the flowing nerve impulses get the sum of the two potentials "(E_g+ E_i)" and, hence, the power that motivates the motion of the nerve impulses can be calculated as follows:

$$\dot{W} = \dot{S} * (E_g + E_i) \qquad (10)$$

Where:

$$\dot{S} = \dot{s} * A_{axon} \qquad (11)$$

Where $\dot{s}$ is the specific rate of growth of entropy per unit area of the neural fibers, traditionally called the current density, and A_{axon} is the cross-0section area of the axon.

According to Eq. (10), the impulses power increases by injection of electric charges that have a negative potential causes the measured excitation of the neural system or the acceleration of the flow of nerve impulses. While, if the injected charge has a positive potential (anode), the measurements show such charge tends to inhibit the flow of the nerve impulses [45]. This can be also plausibly explained by the principles of superposition. In this case, the negative driving potential of the nerve impulse will be reduced by the positive potential of the injected impulses. So, the electrical or driving potential of the nerve impulses equation will be "(E_g-E_i)", and power that drives the nerve impulses will be decreased according to following:

$$\dot{W} = \dot{S} * (E_g - E_i) \qquad (12)$$

So, such reduction of the power of the nerve impulses by the positive potential of the injected current represent a plausible explanation of inhibiting the reduces the source of the measured inhibit of the neural system. Other measurements found different influences of selecting stimulation sites on the brain where there are areas of white matter and areas of grey matter, Fig. (7) [46]. Such difference can also be plausibly explained according to the newly introduced definitions of the nerve impulses and the neuron power. When the stimulation site is near the white matter, Fig. 7, where most highly myelinated axons are there, it is most likely to increase the driving potential of the nerve impulses inside axons, according to Eq. (10), and leads to the measured excitement of the neural system.

While, if it is near the grey matter where there are highest neural bodies, the measured inhibit of the neural system is due to disturbing the process of converting the metabolic heat into electric charges in the neurons and influencing the transmembrane temperature difference.

Figure. 7. Brain regions of a fully developed human (20 years) [46].

Power Threshold for Stimulation of Neural Systems

According to the previous review, we recognized the neural fibers as electric conductors which allow the flow of nerve impulses as electric charges. Based on computed models of the human motor cortex, the current density thresholds for stimulation range from approximately 2.5 A/m² (at 50 Hz) to 6 A/m² (at 2.44 kHz) [47]. We identified in our study the rate of growth of entropy per unit of area of fibers, denoted as "s_{neural}" and traditionally called the current density, as a property of the neural fiber where such rate defines the capacity of a unit area of the axon to allow growth of the associated entropy as irreversibility, dissipated as heat, per unit area [34]. Accordingly, the computed threshold current density determines such current density as a property of the neural fibers. This means that the measured threshold current density that excites the neural fibers is equal to the fiber's current density. Hence, if the measured potential that excites the brain's neural system is in the range of 15 – 30 mV, we can estimate the ratio between the required threshold power density which can excite the neural system and has a potential of 15 – 30 mV and current density through the axon "$\dot{s}$," and the axon power density that has an equal current density "$\dot{s}$" and have a potential 60 mV is as follows:

$$\frac{Threshold\ power}{Axon\ Power} = \frac{(15-30)*\dot{s}_{n.fiber}}{60*\dot{s}_{n.fiber}} = 0.25 - 0.5 \qquad (13)$$

So, the injected power density that excites the neural system is in the range of 25% to 50% of the axon power density. This ratio indicates the importance of the potential of the injected power that determines the safety of the neuromodulation processes.

According to the previously published data, we can estimate limits of the threshold power that may excite the neural system is equal to the current density of th neural fibers as follows:

$$\dot{W}_{axon} = 2.5 * 1.5 \,.\, 10^{-6}\, {}^{Watt}/_{V\, *\, mm^2} * 15\ .\, 10^{-3} = 56.25 \,.\, 10^{-9} \quad \text{Watt/mm}^2 \qquad (14)$$

To:

$$\dot{W}_{axon} = 6 * 6 *\ 10^{-6} * {}^{Watt}/_{Volt\, *\, mm^2}\ 30 *\ 10^{-3} = 1080 \,.\, 10^{-9} \quad \text{Watt/mm}^2 \qquad (15)$$

Multiplying the determined triggering power by the time injection time of which in in the range of 200 µ. sec - 300 µ. sec., we get the following value of the threshold injected energy as:

$$Q_{injected} = 56.25 \,.\, 10^{-9} * 200.\, 10^{-6} \sim 11.2 \,.\, 10^{-9}\, m.Joule/mm^2 \qquad (16)$$

Or

$$Q_{injected} = 1080.\ 10^{-9} * 300 \,.\, 10^{-6} = 324 \,.\, 10^{-9}\ {}^{m.Joule}/_{mm^2} \qquad (17)$$

According to the previously estimated injected energies, we find that both estimated values by Eqns. (16, 17), may have unsafe thermal effect on the neural system if the duration of injection exceeds a limited time [48]. So, the associated of growth of entropy by the flow of the injected or induced electric currents, which is dissipated as heat through the axons, is not representing a source of damage to the neural system unless the injection potential ot time is keeping the safety level. So, the potential of the injected energies is so effective when increasing the injected power density more than the half of the neuron power density may lead to damage the triggered muscles by superordinary power.

Conclusions

Reviewing the innovative definitions of:

1. The flow of electric charges as flow of EM waves which have an electric potential and whose flow is associated by growth of entropy
2. The nerve impulses as EM waves hat have an electric potential, traditionally called action potential, and whose flow is identified as electric signals and associated by growth of entropy.
3. The neuron as a generator of the nerve impulses, as a thermo-cell, by deploying its transmembrane Seebeck effect to converting the thermal potential of its metabolic heat into electric potential.
4. The axons as transmission lines that conduct the nerve impulses to trigger concerned muscles.
5. The rate of growth of the entropy of neural fibers per unit area, traditionally called the current density, is a property of the neural fibers.

We achieve the following conclusions:

1. The generated flow of nerve impulses, as electric signals from the neurons, have the same nature as the direct or induced modulating electric currents.

2. Proper understanding of the neuromodulation as interference between two electric currents according to the principles of superposition which found plausible explanation of the measured results as follows:

a. If the injected current has negative potential (cathode), the driving potential of the nerve impulses will increase by adding the negative potential of the injected current to the negative potential of the generated nerve impulses. Such increase explains the excitation measured in this case.

b. If the injected current has positive potential (anode), the driving potential of the nerve impulses will decrease by reducing the positive potential of the injected current from the negative potential of the generated nerve impulses. Such decrease explains the inhibit measured in this case.

3. Proper understanding of the neurons as generators of nerve impulses and the nerve impulses as electric charges driven by electrical potentials, the measured dependence of excitation of the neural system on the stimulation site on the brain can be plausibly explained as follows:

a. When the stimulation site is near the white matter, where most highly myelinated axons are there, the excitation will depend on the sign of the potential of the injected or induced electric current according to the explained rules in the second conclusion.

b. While if it is near the grey matter, where the highest neural bodies, the stimulation current will disturb the process of converting the metabolic heat into electric charges and inhibit the activity of the neural system.

4. Proper understanding of the rate of growth of entropy per unit area of materials, traditionally called current density, as a property of any material, it was possible to explain the measured threshold current, threshold potential, and threshold power density as follows:

a. The axon has a definite value of the current density, like any neural fiber, that can excite the flow through it.

b. Current density threshold for the stimulation of the neural system should be equal to the current density of the neural fibers in order to be effective in excitation of the neural system.

c. The safety threshold potential of the injected current should be in the range 15 - 30 m. Volt, as the threshold power density in this case will equal 25 % to 50 % of the power density in the neural fibers or axons. Higher values of the threshold potential will lead to superheating the neural fibers by the associated growth of entropy with modulating electric current

5. Studying an effect of the associated growth of entropy by the injection of external electric current, which is dissipated as heat, we found it has limited thermal effect by limiting the injection time and the threshold power.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this pa per. References

References

1. Chen, Y., Gong, C., Tian, Y., Orlov, N., Zhang, J., Guo, Y., Xu, S., Jiang, C., Hao, H., Neumann, W. J., Kühn, A. A., Liu, H., & Li, L. (2020) Neuromodulation effects of deep brain stimulation on beta rhythm: A longitudinal local field potential study. Brain Stimulation, 13: 6
2. Avery M. C., Krichmar J. L. (2017) Neuromodulator systems and their interactions: A review of models, theories, and experiments. Frontiers in Neural Circuits, 11: 1-29.
3. Matija M, Cindi M., Stephanie N. Iwasa, Zariffa J., Milosevic L., Taufik A. (2025) Valiante, Joaquín A., Hoffer and Milos R. The mechanisms of electrical neuromodulation. J Physiol, 603: 247 – 284.
4. Abdelhady S., Abdelhady M. S. (2015) An Entropy Approach to the Natures of the Electric Charge and Magnetic Flux. Journal of Electromagnetic Analysis and Applications. 7: 265- 275.
5. Abdelhady S. (2013) An Entropy Approach to Tesla's Discovery of Wireless Power Transmission. Journal of Electromagnetic Analysis and Applications, 5: 157-161.
6. Tate O, Cheneler D., Taylor J. (2019) A thermal-electrical analogy model of a four-floor building. IFAC Papers On Line 52: 91 - 96.
7. Faraday M. (1846) Experimental Researches in Electricity, Nineteenth Series, Phil. Trans. R. Soc. Lond. 136: 1-20.
8. Benjamin D., et al. (2018) Thinking about the nerve impulse: A critical analysis of the electricity centered conception of nerve excitability. Prog Neurobiol. 69 (172): 1 – 20.
9. TD. Albright, TM Jessell, ER. Kandel, et al. (2005) Neural Science A Century of Progress and the Mysteries That Remain. Neuron Raghavan. 1: 1-5.
10. Yuqing Liu, Shuai Zhang, Yuetong Zhou, Mark A. (2020) Buckingham, Leigh Aldous, Peter C. Sherrell, Gordon G. Wallace. Advanced Wearable Thermo-cells for Body Heat Harvesting. Adv. Energy Mater. 10: 1- 10.
11. Van Herwaarden A, Sarro P. (1986) Thermal Sensors Based on The Seebeck Effect, Sensors and Actuators.10: 321-346.
12. Baigrie B. (2007) Electricity and magnetism, A historical perspective. Green Wood Press. ISSN 1559-5374
13. S. Abdelhady. (2017) Thermodynamics: Fundamentals and its Application in Science, Auris Reference; 1st edition. London (UK), ISBN-10: International Textbook In Science.
14. RA. Serway, JW. Jewett. (2020) Physics for Scientists and Engineers. Brooks Cole.
15. S. Abdelhady. (2015) An Advanced Review of Thermodynamics of Electromagnetism. International Journal of Research Studies in Science, Engineering and Technology. 3: 10-25.
16. S. Abdelhady. (2012) Thermodynamic analysis of energy flow in optical fiber communication systems, Appl Phys Res. 4: 1 – 12.
17. Jewett J, Serway A. (2000) Physics for Scientists and Engineers, Thomson, and Brooks.
18. Faraday M. (1846) Experimental Researches in Electricity, Nineteenth Series, Phil. Trans. R. Soc. Lond. 136: 1-20.
19. Abdelhady S. (2023) Proper Understanding of the Natures of Electrons, Protons, and Modifying Redundancies in Electro-Magnetism. Journal of Electromagnetic Analysis and Applications, 15: 59-72.

20. Abdelhady S. (2010) A Fundamental Equation of Thermodynamics that Embraces Electrical and Magnetic Potentials. J. Electromagnetic Analysis & Applications, 2: 162- 166.
21. Alzeer J. (2024) Beyond Disorder: A New Perspective on Entropy in Chemistry. American Journal of Medicinal Chemistry. 5: 1-5.
22. Abdelhady S. (2025) Introducing Entropy as a Fundamental Property of the Electric Conductors. 15th International Conference on Electrical), Engineering (ICEENG IEEE explore: 1- 6.
23. Abdelhady M. S., Abdelhady S. (2026) A new approach for formulating the transport phenomena. International Communications in Heat and Mass Transfer. 172: 1 – 6.
24. Abdelhady S. (2020) Electric and Magnetic Energies in the Human Body. International Journal of Applied Energy Systems. 2: 44-52.
25. Sekerka R. E. (2015) Thermal Physics - Thermodynamics and Statistical Mechanics for Scientists and Engineers. Elsevier.
26. Adesakin E. et. Al, (2019) Current Density, Electron Mobility and Drift Velocity of Metals. Jour of Adv Research in Dynamical & Control Systems. 1: 1-20.
27. Adesakin G. E. (2019) Current Density, Electron Mobility and Drift Velocity Of Metals, Journal of Advanced Research in Dynamical and Control Systems.11: 1 – 12.
28. Nakayamaa K., et. Al. (2023) Visualization of axonal and volume currents in median nerve compound action potential using magneto neurography. Clinical Neurophysiology. 152: 57-67.
29. Abdelhady S. (2020) Innovative Definition of Nature of the Nerve Impulses. Ain Shams Engineering Journal, 11: 473-477.
30. Radivojevic M., Felix F., Altermatt M., Müller J., Hierlemann A., Bakkum D. J. (2017) Tracking individual action potentials throughout mammalian axonal arbors. eLife 6: 1-23.
31. Abdelhady M. S, Abdelhady S. (2024) Diffusion Equations of the Electric Charges and Magnetic Flux. Journal of Electromagnetic Analysis and Applications. 16: 69-83.
32. Purves D, Purves D, Augustine GJ, Fitzpatrick D, et al., (2001) editors. Neuroscience. 2nd edition. Sunderland (MA): Sinauer Associates. Long-Distance Signaling by Means of Action Potentials.
33. Abdelhady S. (2025) Proper Understanding of the Axon as a Transmission Line That Conducts the Neuron's Power. Japan Journal of Medical Science. 6: 293 – 298.
34. R. Bradely, J. P. Wiksow. (1985) The Magnetic Field of a Single Axon, A Comparison of Theory and Experiment Biophys. J. 48: 93-109.
35. J. Zhang. (2019) Basic Neural Units of the Brain: Neurons, Synapses and Action Potential. IFM Lab Tutorial Series. 5: 1–38.
36. Paul L, Nunez S, R. (2005) Srinivasan Electric Fields of the Brain. The Petrophysics of EEG, second ed.. Oxford University Press, Oxford
37. Li, Meng et al., (2021) High-efficiency thermos-cells driven by thermo-electrochemical processes, Trends in Chemistry, 3: 561-574.
38. Tanimoto, R., et al. (2016). Detection of Temperature Difference in Neuronal Cells. Scientific Reports, 6, Article No. 22071.
39. H. Bertille. (2011) Ionic Basis of Resting and Action Potentials, Supplement 1. Handbook of Physiology, The Nervous System, Cellular Biology of Neurons, Wiley.
40. Pala A., Petersen C. C. (2018) State-dependent cell-type-specific membrane potential dynamics and unitary synaptic inputs in awake mice. eLife. 7: 1 – 12.
41. A. Abdelhady. (2022) Machine Records of the Neurology Clinic. Records of Aswan University-Hospital. 5:1217- 1218.
42. Ryan D. (2006) Toward a cognitive-historical understanding of Michael Faraday's research: editor's introduction," Perspect. Sci, 14: 1-10.
43. Leferink F. (2015) Conducted interference, challenges, and interference cases," IEEE Electromagnetic Compatibility Magazine. 4: 78–85.
44. Balbinot G.M, et. Al, (2025) The mechanisms of electrical neuromodulation Gustavo. J. Physiol. 2: 247 – 284.
45. Basser PJ, Roth BJ. (2000) New currents in electrical stimulation of excitable tissues. Annu Rev Biomed Eng. 2:377-97.
46. Zhang K, Sejnowski T. J. (2000) Universal scaling law between gray matter and white matter of cerebral cortex. PNAS. 97: 5621 – 5626
47. Cassarà M. et. Al. (2025) Recommendations for the Safe Application of Temporal Interference Stimulation in the Human Brain Part II: Biophysics, Dosimetry, and Safety Recommendations Antonino. Bioelectromagnetic. 46: 1-20.
48. Cassarà, A. M., E. Neufeld, S. Regel, and N. Kuster. (2023). "EM Exposure During Non-Invasive Brain Stimulation Applications: Impact of Uncertainties on Treatment Relevant Metrics." Neuromodulation Technology at the Neural Interface. 26: 1-20.

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