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# Proper Understanding of the Axon as a Transmission Line That Conducts the Neuron's Power to Muscles

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## Abstract

Recognizing a nature of the nerve impulses as electromagnetic waves that are driven by their electric potential and associated by growth of entropy, as electric charges, we define the axons as electric conductors that have electric diffusivity, entropy, and rate of growth of entropy as their properties. Such understanding leads to define the axons as transmission lines that conduct the neuron's power to the muscles for triggering the release of calcium and initiating the muscle contraction. We measure in this study, by an Ammeter, the rate of growth of entropy through a sciatic nerve of a chicken. So, we find the rate of growth of entropy per unit area of neural fibers, as 0.4 Watt/mmm$^2$ The used measurement setup of the nerve's resistance represents an experimental proof of the function of the nerves as a transmission line. We found such understanding is more plausible than the traditional hypothesis of the ATP synthesis as a source of the triggering energy for muscle's contraction which violates laws of thermodynamics. Understanding the flow of the nerve impulses or charges through the neural fibers as a diffusion process, we found such velocity mainly depends on the electric diffusivity of the neural conduits and the rate of growth of entropy through them.

**Key words:** Entropy, Electric Charges, Neuron's Power, Nerve Impulses, Action Potential, ATP synthesis, Transmission line

## Introduction

According to the introduction of the Hodgkin-Huxley model of action potential in the 1950s, the generation and propagation of the nerve impulses are found as solely electrical events [1]. A newly introduced volume conductor (VC) model considered the neural fibers as conductors of electric charges. This model finds plausible explanation of the measured magnetic field produced by the propagating electric potential across such fibers [2]. As proof of validity of such introduced definition of the neural fibers as electric conductors is the measured internal electric resistance of axons and their internal conductivity [3]. The traditional definition of electric charges as electron criticizes the definition of the nerve impulses as electric charges while the neuroscientists call the flow of the nerve impulses as electric signals [3]. According to a proper definition of the flow of electric charges as flow of energy in the form of electromagnetic (EM) waves that have electric potential, it was possible to define the nerve impulses as electric charges and to consider the observed propagating action potential through the neural conductors as their electric potential [4, 5]. In analogy of the definition of heat flow as EM waves that are associated by growth of entropy, we found the flow of electric energy as EM waves which is also associated by growth of entropy [6]. Accordingly, we found the materials that conduct electric and thermal energies have the entropy as a property whether they are used as thermal or electric conductors [7]. Accordingly, we analyze in this study the entropy as a property of the neural fibers as it is defined as electric conductors.

However, the traditional references, that ignore the nature of nerve impulses as energy, consider the flow of nerve impulses as movement of independent action potentials [8]. Physically, the potential is an effect or property of energy that drives its flow from high potential to low potential and it is not a frontier of nondriven energy [9]. So, the presented study focusses on a new approach for proper understanding of the nerve impulses as energy whose flow is driven by its electric potential.

In the present study, we start by introducing the recent definition of the electric charge as EM wave that have electric potential and are associated, as heat, by growth of entropy. We also review previous studies that found the entropy and its rate of flow per unit area, traditionally called current density, as a property of the materials of electric conductors [7]. Then, we introduce in the present study a measurement setup that involves an Ammeter to find the rate of growth of entropy in the sciatic nerve of a chicken, and then, the rate of growth of entropy per unit area, traditionally called the current density, of the neural fibers. According to a recent study, the current density, or the rate of growth of entropy per unit area, is a common property of the material of the electric conductors [7]. Hence, we may consider the estimated current density of the of the sciatic nerve as a common property of the neural fibers.

We found the introduced setup for measuring the rate of growth of entropy through the sciatic nerve shows of the function of such nerve as a transmission line that conducts the generated nerve impulses in the neurons, as a power supply, to the contracting muscles, as motors [10]. However, such approach contradicts the traditional hypothesis of ATP synthesis which are revealed from a hypothetical mechanism that disagree available biochemical and biophysical data and violate both the first and second laws of thermodynamics [11]. The source of such confusion is the traditional definition of the action potential as an electrochemical effect while it is the potential of propagating nerve impulses or electrified energy.

Traditional references calculate the velocity of flow of nerve impulses as velocity of triggered action potentials through neural fibers recorded as propagating waves [12]. Following the newly introduced definition of the electric charges as flow of electromagnetic waves driven by its electric, potential, we investigate in our study the recorded waves as diffusion of electric energy in the form of nerve impulses. Hence, we will find the major parameters that determine such velocity according to the characteristic diffusion equation.

## Characteristics of the nerve impulses as electric charges

According to an analogy of the laws that characterize the flow of heat and electric charges in addition to results of Faraday's experiments, the electric and heat fluxes were defined of a common nature as flow of electromagnetic waves that have electric or thermal potentials [13]. The success of Faraday in converting a ray of light into a beam of electric current when passing through an electric field represents a proof of the flow of electric energies as EM waves that have an electric potential. According to the second law of TD the transfer of heat through conductors is associated by a growth of entropy. Such growth leads to increase the randomness of the spatial microstructure of the conducting materials which defines the entropy as a property of such conducting material [14]. The growth of such property of conducting materials is associated by the flow of thermal energy, or heat, through such material according to the following equation [15]:

$$\delta Q_{th} = T\, dS \qquad (1)$$

Recognizing the flow of electric charge as flow of energy like the flow of heat, the flow of electric energy into the conductors is also associated by increase of their entropy according to the following equation in analogy to Eqn. (1) [16]:

$$\delta Q_{elec} = E\, dS \qquad (2)$$

The unit of entropy according to the previous equations is Joule/Volt as the volt is the unit of measurement of thermal or electric potentials when using a thermocouple. The rate of growth of entropy during the energy transfer processes is found by dividing both sides of Eqns. (1) or (2) by the differential of time at constant potential as follows:

$$\dot{S} = \frac{\dot{Q}}{E} \quad \text{Watt/Volt} \qquad (3)$$

The unit of Ammeter's measurement is quotient of the electric power divided by the electric potential, i.e., Watt/Volt. We find such unit is identical to the unit of the rate of growth of entropy through conductors as identified in Eq. (3). So, it was concluded in previous studies the Ammeters measure the rate of growth of entropy through conductors which is associated by the process of transmission of electric energy or charges [16]. So, the Ammeter's readings do not measure the rate of flow of electrons as the electrons are particles whose rate of flow should be kg/sec. Defining the electric charge as energy, Ammeters don't read the rate of flow of electric charges as such rate in this case should have the unit Watt, while the used unit of Ammeter's measurement is Watt/Volt. As it is unlogic to define the Ammeter as a device that measures the rate of flow of charges, in Watt, or the rate of flow of electrons in kg/second, we should define the Ammeter measures the rate of growth of entropy in Watt/volt which is associated by the flow of electric charges or energy. The traditional definition of the electric charges as electrons led to the duality confusion when explaining the photovoltaic effect and led to other physical redundancies as mentioned in previous studies [17]. As a sufficient proof of the error of defining the electric charges as electrons is the measured drift speed of electrons in good conductors, as copper, that doesn't exceed 1 m/sec while the measured speed of electricity, or electric energy, approaches the speed of EM waves [18]. The heat radiation, as EM waves, possesses its thermal potential which drives its flow from high temperature or potential to a low potential. So, the velocity of flow of heat radiation and its driven potential is the velocity of EM waves. Similarly, the propagation speed of an electric field, when considered as an electromagnetic wave, also has the speed of light where this speed is derived from Maxwell's equations and is a fundamental property of electromagnetic waves [19]. The innovative definition of the electric charge as electric energy that possesses its electric potential or field is found equal to the Maxwell's speed of propagation of the electric field and both speeds approach the speed of light like the heat radiation [20, 21]. Such proper definition the electric current as EM waves that have either positive or negative potentials and are associated by growth of entropy also leads to plausible definitions of the positive and electric charges, the electrons, and the protons [22].

As an approach to define the electric current as EM waves of electric potential, the Maxwell's wave equations are modified by replacing the time in such equations by entropy [23]. Such replacement transfers the traditional coordinates of the Maxwell's equations into energy coordinates. The flow of the electric charges can be analytically represented as a solution of such modified Maxwell's wave equations in the form EM waves that have following initial equations [24]:

$$E_{\text{at t or s=0}} = E\_0 \qquad (4)$$
$$H_{\text{at t or s=0}} = 0 \qquad (5)$$

The found solution is as follows:

$$E(r,s) = g_1\ (\omega\, s - k\, r) + E_0 \qquad (6)$$
$$H(r,s) = g_2\ (\omega\, s - k\, r) \qquad (7)$$

The solution of Eqns. (6) and (7) is represented graphically in Fig. 1 [24]. Such representation shows the positive charge as EM wave whose E coordinate has a positive value + Δ E.

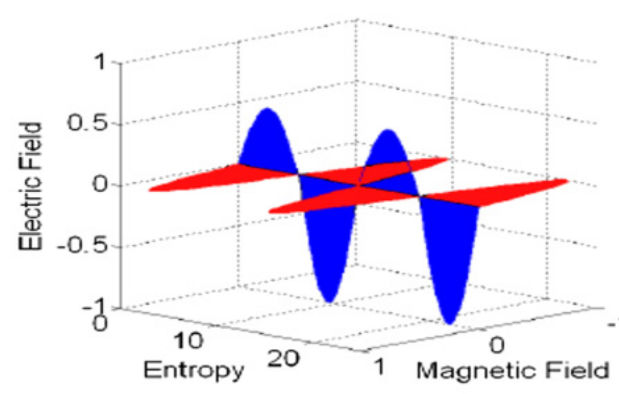


**Figure. 1** Graphical representation of a Positive electric charge distinguished by the oscillation around an entropy axis whose E coordinate "Electric Field" has a positive value + Δ E [24].

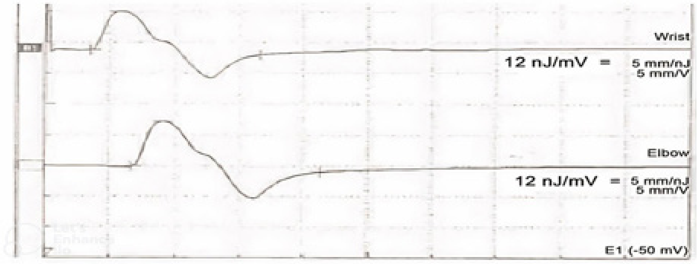


**Figure. 2.** A machine record of a stimulating electric charge injected through a neural system inside wrist and elbow of a patient. The ordinate shows the potential of the electric charge in Volt and abscissa shows the entropy growth during the stimulation Joule/Volt as the product of the Ammeter's reading times the time of injection [25].

Figure 2. shows a record of an injected stimulus charge used in neural diagnosis of patients as shown in the form of a wave oscillating about an axis of positive potential ordinate, i.e., it is a positive charge [25]. The abscissa records the rate of growth of entropy through the neural fibers during the flow of the charge in n. joule/volt, and the ordinate records the variation of the potential of the injected charge during the process in Volts. Such experimental record in Fig. 2 is identical to the analytical solution of the modified Maxwell's equations in Fig. 1. Such similarity proves the truth of considering of flow of electric charges, or electric current, as flow or EM waves that have electric potential. According to the data on Fig, 2, it is possible to read the recorded growth of entropy during one wave = $\Delta$ S = 3 nano-Joule/volt and the recorded time duration of the pulse = 0.2 milli Second.

According to a previous study, the measured rate of growth of entropy per unit area per unit driving potential, traditionally called the current density, is a property of electric conductors [26]. So, each material has a specific value of the rate of growth of entropy per unit area such rate where the Cupper has a rate of 1.6 $\frac{Watt}{Volt}\Big/_{mm^2}$ and Aluminum has a rate of 1.0 $\frac{Watt}{Volt}\Big/_{mm^2}$ [27].

So, the electric charges are recognized as electromagnetic waves that are driven by their electric potential and associated by growth of entropy. However, the barrier that criticizes the neuroscientists to define the nerve impulses as electric charges is the wrong definition of the electric charges as electrons while they measure the flow of such pulses as electric signals [27]. Such definition of the electric charges as EM waves that have electric potential finds plausible explanations of the measured magnetic field because of flowing nerve impulses as electric charges through organic axons. Accordingly, we define in this study the nerve impulses as electromagnetic waves that are driven by their electric potential and associated by growth of entropy, as electric charges.

## Electric Characteristics of the neural conductors

The recently introduced the "Volume Conduit" or "Volume Conductor" model may represent a theoretical framework that simulate the electrical behavior of biological tissues, including neural fibers as a way of travel of the nerve impulses as electric charges within a volume of organic tissues [28]. Such model is applied to explain the measured magnetic field because of travelling the measured electric signals through the neural fibers. Bradely was able to measure the electric resistance of an axon of 19.3 k 'Ω/mm implying a value for the internal conductivity of 1.44 'Ω-1 m-1 [29]. Such records assure that the neural fibers can conduct electric charges and that the electric charges are not electrons but are EM waves that can flow through organic fibers and have recorded electric potentials.

According to the previous review, we identify the nature of neural fibers as conduits of electric charges, or electric conductors, and the definition of the nerve impulses as EM waves that have action potential and are associated by growth of entropy. So, we should define the entropy as a property of the neural conduits that grows by the associated nerve's entropy as they are defined as electric conductors.

However, the electric conductors also have, according to a previous study, the rate of growth of entropy per unit area, or as traditionally called the current density, as a property of its material [7]. So, the neural fibers also have the same value of the current density, or the rate of flow of entropy per unit area as a common property of the neural fibers. Accordingly, we define in this study the axons as a conductor which can conduct the nerve impulses as electric charges generated in the neuron, driven by its electric potential and associated by growth of entropy through such axons. Such growth of the axon's entropy is interpreted as a loss of the neuron's power by the electric resistance of the axon and leads to a drop of the impulse's potential [30].

## Measurement of the electric characteristic of the sciatic nerve of a chicken

To find the rate of flow of growth entropy per unit area of the neural fibers as one of the properties of neural fibers, we measured the rate of growth of entropy in a sciatic nerve of a chicken. So, we installed the electric circuit shown in Fig. 3 which connects the sciatic nerve of a chicken "P-N" to the power supply "P."

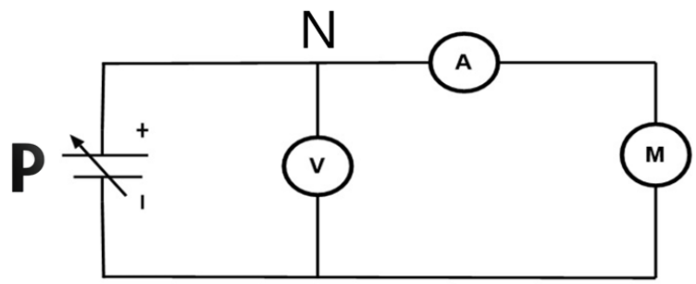


**Figure. 3**. Layout of a test rig for measurement the electric power flow through a connected sciatic nerve of a chicken PN, from a d/c power supply P to an electric motor M, through an Ammeter A.

The circuit, as shown, also involves an Ammeter "A," an electric motor "M" and a Voltmeter "V." We follow in our study a proper understanding of the function of the Ammeter as a device that measures the capacity of the conductor to allow flow of electric power per unit electric potential or the ability of the conductor to allow flow of measured the rate of growth of entropy during the transmission of energy in Watt/volt. Such capacity or ability also represents a property of the material of the conductor, or the neural fibers, according to the introduced definition of entropy as a property of electric conductors.

The measured diameter of the nerve was 2 mm, and the inserted length was 1 cm. We measured the resistance of such verse as 40 k. 'Ω/cm. The recorded Ammeter's reading is 1.25 milli Watt/Volt. According to a modified form of Ohm's law, we determine the potential drop across the nerve according to the following equation [7]:

$$V_s - V_A = S^* R_{nerve} = 1.25 .10^{-3} * 40 .10^3 = 50 \text{ Volt} \qquad (8)$$

According to the measured potential of the outpower from the power supply as 65 Volt, and the measured potential of the input power to the electric motor as 15 Volt, the potential drop across the nerve of the value 50 is correctly estimated according to equation (8) which means the ability of the nerves to conduct electricity and the nature of electricity as waves which can flow through the organic nerves.

However, the main objective of our experiment is to determine the rate of growth of entropy per unit area of the neural fibers, or the current density, of the neural fibers and to find a reference value of a new neurodiagnostic property.

We may calculate the rate of entropy growth per unit area of the nerves as follows:

$$\dot{S}_{nerve} = \frac{\dot{S}_{nerve}}{A=\pi*{}^{d^2}/_4} = \frac{1.25\,.10^{-3}}{\pi*{}^{2^2}/_4} \quad (9)$$

Substituting the value of the diameter of the nerve of 2 mm, we find the rate of growth of entropy per unit area through nerves as follows:

$$\dot{S}_{nerve} = 0.4\ {}^{Watt}/_{Volt}/_{mm^2} \quad (10)$$

According to available data, as the axon diameter ranges are 0.1 to 10 µ.m

So, we can calculate the value of rate of entropy growth through an axon of diameter 0.1 µ.m as follows:

$$\dot{S}_{axon} = \dot{S}_{nerve} * A_{axon} = 0.4 * \pi * {}^{1*(10)^{-4*2}}/_4 = 3\ nano\ Watt/Voltfollow \quad (11)$$

This value is equal to the estimated growth rate of entropy in axons according to a measured generated magnetic field in previous studies [31]. The achieved conclusion means the rate of growth of entropy per unit area through nerves as is 0.4

$${}^{Watt}/_{Volt}/_{mm^2}$$

Hence, we may use this value to find the rate of growth of entropy though other nerves or neural fibers of different cross sections.

The shown circuit in Fig. models the function of the axons as the transmission line that conducts the neuron's power that the represent the neuron by the power supply "P", and the muscles the triggers the initiation of the release of calcium for the contracting muscles by the motor "M".

The shown circuit in Fig. 3 models the function of the axons as the transmission lines that conducts the neuron's power that the represent the neuron by the power supply "P", and the muscles the triggers the initiation of the release of calcium for the contracting muscles by the motor "M". According to this model, A portion of the neuron's power and its transmembrane potential is dissipated in growing the axons entropy as electric conductors which can be estimated as follows:

## Discussion of the traditional hypothesis of ATP synthesis as a source of biological energy

Adenosine triphosphate (ATP) is thought as a biological energy source whose synthesis is utilized in a mechanism of interaction of an action potential for triggering the muscle contraction [31]. According to biological thermodynamics of ATP synthesis, its introduced mechanisms violate both the first and second laws of thermodynamics as the action potential, which is defined as an effect, cannot initiate a release of triggering energy [31]. So, the conducted charges along the axon can trigger the intended muscles without the support of a spontaneous source of energy. Understanding the nerve impulses as energy whose potential is the action potential, represents a proper approach that plausibly explains the muscle contraction by the electric energy of conducted nerve impulses. So, we explain the axons as the transmission lines of conducting the nerve impulses, as electric charges. Accordingly, some of the neuron's power and its transmembrane potential are dissipated its allow the flow of triggering energy through the nerves. As discussed, Fig.3 represents an experimental derivation of the innovative explanation of the supply mechanism of energy that involves the neuron as a power supply, the axon as a transmission line and the muscles contraction mechanism as a motor. Such approach depends on the innovative definition of the nerve impulses as EM waves which are recoded as propagating waves which was wrongly defined as propagating action potential as an effect or electrochemical signals [32].

## Diffusion of the nerve impulses

Reviewing the traditional articles that calculate the velocity of flow of nerve impulses that flow as electric signals, we found their studies follow recoded motion of the electric potentials. Such references assume the motion of the potentials of the electric charges is due to electric depolarizations that initiate a series of triggered action potentials in successive segments of axons [33]. They recorded similar waveforms, as shown in Fig. 5, which should be explained as EM waves generated in the neurons and flow as nerve impulses in the form of EM waves whose potential is oscillating around a mean negative value [34]. However, they considered these records belong to independent triggers of independent action potentials of unknown source of energy. Such approach was unable to find a plausible explanation of the flow of the nerve impulses as continuous flow of energy in the form of electric signal or to define the source of such energy [35].

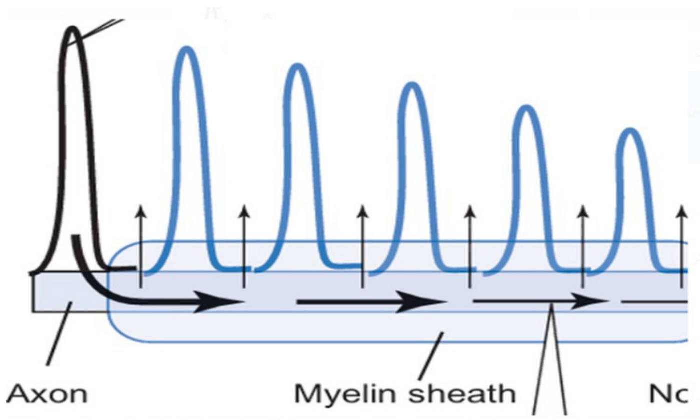


**Figure. 5.** Recoded travels of the action potentials down the axon [34].

According to the traditional references, the measured propagation velocities of the action potential are in the range from 100 meters per second (580 miles per hour) in large, myelinated axons to less than a tenth of a meter per second (0.22 miles per hour) in small, unmyelinated axons [35]. Such velocities cannot be explained because of triggering potentials as traditionally explained. In a recent study that analyzed the flow of nerve impulses as diffusion of electric energy, it achieved the following diffusion equation [35]:

$$V_{imp}(x,s) = V_{membrane} - B\, e^{-x/\delta} \cos\left(\omega\ {}^{s}/_{\dot{s}} + {}^{x}/_{\delta}\right) \quad (13)$$

Where: $V_{imp}$ (x,s) is the potential of the propagating EM waves of the flowing nerve impulses as a function of the propagation axis " x" and the entropy growth "s", ω is the angular velocity of the ECG measured wave, $V_{membraneis}$ the initial potential of the generated transmembrane potential in the neurons, (s ) is the measured rate of growth of entropy by Ammeters, α_n is the diffusivity of the neural fibers, and δ is the skin depth defined as [36]:

$$\delta = \sqrt{\frac{2\,\alpha_n}{\omega}} \qquad (14)$$

According to Eqn. (13), the velocity of diffusion of the nerve impulses, as electric charges, depends on the parameters $V_{membrane}$, α_n, ω , and s. Denoting such velocity as $X_{nerve\ impulses}$, the concluded velocity of the nerve impulses, or the associated action potential, can be determined experimentally according to following equation:

$$\dot{X}_{nerve\ impulses} = f(V_{membrane}, \alpha_n, \omega, \dot{s}). \qquad (15)$$

## Conclusions

1. We defined the entropy in this study as a property of the neural fibers whose differential is equal to the quotient of the energy of the flowing nerve impulses divided by its electric potential.
2. By an Ammeter, we measure the rate of growth of entropy associated by the flow of nerve impulses per unit potential through a sciatic nerve of a chicken.
3. Accordingly, we determined the rate of growth of entropy per unit area of neural fibers, traditionally called the current density, as 0.4 $\mathbf{Watt}/\mathbf{Volt}/\mathbf{mm^2}$.
4. According to the involved setup for measurement the entropy flow through the nerve impulses, we define the axons as the transmission lines that conducts the neuron's power to the muscles. Such measurement also defines the neuron as a power supply and the muscles as the motor that moves the bones.
5. The definition of the axons as transmission lines of electric charges, that have their driving potential for triggering the muscles, leads to investigate the physical foundation of the traditional hypothesis of the ATP synthesis.
6. We find the assumed mechanism of the ATP synthesis is violating laws of thermodynamics as the action potential, which was introduced as an effect, cannot initiate a triggering energy in the muscles.
7. We defined the flow of the nerve impulses though the neural fibers as a diffusion process. So, we found the velocity of flow of the nerve impulses, or the velocity of propagation of its associated entropy, is a function of the electric diffusivity of the neural fibers and the measured rate of entropy growth through such fibers.


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## Conflict of Interest

The Author has no conflict of interest with any others.

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