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ELECTROMAGNETIC MODELS OF BIOMEDICAL AND BIOCHEMICAL TRANSFERRING, WORKING, AND MEMORIZING POWERS AND FACTORS

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ABSTRACT

Introduction: Understanding how neurons process, store and transfer information and powers are very helpful to prevent and (or) cure diseases of thinking and memorizing. However, the mechanisms how neurons think or memorize are still not completely clear in perspective views of biomedical engineering, biochemistry, and biophysics, to our knowledges.

Methods: Based on the solid theories of the electromagnetics, electrodynamics, and electric circuits, as well as published biochemical and biological data, we theoretically investigate how biological cells (especially neurons) work, memorize and transfer information and powers.

Modeling Results: We propose our biochemical electromagnetic models to map the divergence of complex Poynting vector, dissipative and stored powers to transferring, working (thinking, moving, and heating) and memorizing powers. For biochemical electromagnetic (half or open) oscillators or resonators (e.g., neurons, myocardia or synapses), we propose our electromagnetic models of four biochemical factors: the first one is the working factor that describes the information and power processing efficiency; the second one is the memorizing factor that describes information and power storing efficiency; the third one is the transferring-out factor that describes the real (average) information and power transferring-out efficiency; and the fourth one is the transferring-in factor that describes the imaginary information and power transferring-in efficiency.

Conclusion: We believe our models will be helpful to prevent and (or) cure diseases of thinking and memorizing as well as to understand how neurons process, store and transfer information and powers, because our models are almost consistent with the first and second laws of thermodynamics, theories of Prigogine's dissipative structures and Lyapunov's stabilities.

Keywords: Information; Neurons' Thinking and Memory; Poynting Complex Vector and Theorem; Maxwell's Equations; Laplace Transforms; First and second laws of thermodynamics; Prigogine's Dissipative Structures; Lyapunov's Stabilities.

1 INTRODUCTION

Understanding how biological cells (especially neurons) process, store and transfer information and powers are very helpful to enhance human abilities of thinking and memorizing and to prevent and (or) cure diseases of thinking and memorizing, as well as to raise levels of artificial intelligence (AI).

In some of our previous studies, to understand how biological cells (especially neurons) work and memorize in perspective views of biomedical engineering, biochemistry and biophysics, based on solid Maxwell's electromagnetic equations and Poynting's vector and theorem *[1* - 5*]* as well as published biochemical data [6 - 8] of neuroscience, we have proposed our electromagnetic models of neurons' processing, storing, correlating, encoding, decoding, transmitting, consolidating, retrieving information [9 - 12].

In our other previous studies, we have introduced the plasma physics into biology (especially neural science); based on plasma hydrodynamic equations [13] and published data [6 - 8] of the molecular biology and biochemistry, at an ionic level, we have modeled the mechanisms of the complete procedures of excitations, dissipations, propagations (oscillations and waves) of the cellular and extracellular fluids in the both natural and forced modes; our models include equivalent circuits with active pumps and passive channels of biochemical ions [11 - 13].

However, the mechanisms how biological cells (especially neurons) think and (or) memorize are still not completely clear in perspective views of biomedical engineering, biochemistry, and biophysics, to our knowledges.

2 METHODS

In this life science oriented study, based on the solid theories of the electromagnetics *[1* - 5*]*, electrodynamics *[14* - 16*]* and electric circuits [17 - 18], as well as published biochemical and biological data [6 - 8], we theoretically further investigate the mechanisms how biological cells (especially neurons) work (think, move and heat), memorize and transfer information and powers, in perspective views of the physics and biochemistry; we also propose correspondent biochemical electromagnetic models.

On the other hand, in physics and mathematics, we discuss our models vs the first and second laws of thermodynamics, theories of Prigogine's dissipative structures and Lyapunov's stabilities [19 -21].

3 MODELS

3.1 General considerations of the macro molecules and biochemical fluids

We consider macro biological or biochemical molecules, such as amino acid, proteins, nucleotides, RNA or DNA, are charged or uncharged particles; the particles move or rest in the cellular (or extracellular) biochemical fluids, e.g., in biological cells (neurons or myocardia) or synapses. We have modeled the biochemical fluids as a liquid quasi-plasma of physics [11 - 13]; the plasma (or electrolyte) is consisted of H_2O, K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^- and other micro ions [6 - 8]; the electric and (or) magnetic fields of the charged particles and plasma are (periodically) alternated, in space-time domains, by cellular biochemical ATP active pumps. The ATP pumps are electric current source (ECS), in equivalent circuits, to periodically drive ion flows or vibrations by compensating the dissipations [11-13].

Periodical signals (functions) with dissipations can be mathematically described with Laplace transforms. Therefore, we assume the electromagnetic fields (and, or electric current densities) can be approximately expressed as complex exponential numbers by Laplace transforms. The general form of complex exponential numbers is [11]:

$$\mathbf{A} = \mathbf{A}_0 \exp[-(\alpha + i\beta) z] \exp[(\delta + i\omega) t] \qquad (1)$$

Where, t and z respectively denote temporal and special variables; i represents the imaginary part; $\mathbf{A}_0$, α, β, δ and ω are real numbers; the bold letter indicates a vector.

3.2 Electromagnetic fields, energies and powers of the biochemical macro molecules and plasmas

When no ECS exists in our considered regions, we model the electric and magnetic vector fields (produced by the charged macro molecules and the plasma) respectively as,

$$\mathbf{E} = \sum_{i=1}^{I} \mathbf{E}_i + \mathbf{E}_p \qquad (2)$$

and $$\mathbf{H} = \sum_{i=1}^{I} \mathbf{H}_i + \mathbf{H}_p \qquad (3)$$

where, **E** and **H** are functions of positions and time, they respectively represent the electric and magnetic vector fields (information intensities) [10, 12] produced by the particles and (or) plasma, subscripts i and p respectively indicate the ith charged macro molecule and plasma.

Poynting vector describes the electromagnetic field energy transfer per unit area, per unit time (power/area = surface power density). Its time instantaneous form is [2],

$$\mathbf{p} = \mathbf{E} \times \mathbf{H} = |\mathbf{E}||\mathbf{H}| \sin(\mathbf{E}, \mathbf{H})\, \hat{\mathbf{e}}_{\perp} \qquad (4)$$

Where, **×** denotes a cross (vector) product; $\hat{\mathbf{e}}_{\perp}$ is a base vector and is perpendicular to both **E** and **H**. The divergence of Poynting vector is useful not only to represent the electromagnetic transferring (volumetric) power densities, but also to derive the electric, magnetic storing and Ohmic (conductive) dissipating (volumetric) power densities [4].

More importantly, the divergence of the complex form of Poynting vector can include the extra dielectric and magnetic dissipating power densities comparing that of the instantaneous form. Therefore, we are using the complex form of Poynting vector, it is,

$$\mathbf{p}_c = (\mathbf{E} \times \mathbf{H}^*) = |\mathbf{E}||\mathbf{H}^*| \sin(\mathbf{E}, \mathbf{H}^*)\, \hat{\mathbf{e}}_{\perp} \qquad (5)$$

Where, the superscript * denotes a complex conjugate and the subscript c denotes a complex number.

Additionally, instead of the real values, we must use the complex forms of permittivity ε_c, permeability μ_c and conductivity σ_c. The Landau's notations for the complex forms are [3, 14]:

$$\varepsilon_c = \varepsilon' - i\varepsilon'', \qquad (6)$$

$$\mu_c = \mu' - i\mu'', \qquad (7)$$

$$\sigma_c = \sigma' = \sigma \qquad (8)$$

Where, superscripts prime and double primes respectively indicate real and imaginary parts of the complex numbers. To simplify our models to quickly obtain our model's meanings in biochemistry as well as physics, we approximate the permittivity, permeability, and conductivity as constants because the frequencies in our studies are very low, though they may be functions of frequencies [14] or tensors [22, 23].

We use a vector identity for the divergence of the complex Poynting vector to derive the transferring, dissipating, and storing power densities, the identity is [2],

$$\nabla \cdot (\mathbf{E} \times \mathbf{H}^*) = \mathbf{H}^* \cdot (\nabla \times \mathbf{E}) - \mathbf{E} \cdot (\nabla \times \mathbf{H}^*) \qquad (9)$$

Where, ∇ and · respectively denote the nabla (del) operator and dot (scalar) product.

We also use two of Maxwell' equations for the derivation, the two equations are,

$$\nabla \times \mathbf{E} = -\left(\mu' - i\mu''\right)\frac{\partial \mathbf{H}}{\partial t} \qquad (10)$$

$$\nabla \times \mathbf{H}^* = \sigma'\mathbf{E}^* + \left(\varepsilon' + i\varepsilon''\right)\frac{\partial \mathbf{E}^*}{\partial t} \qquad (11)$$

Where, Eqs (6), (7) and (8) are used. Substitute Eqs (10) and (11) into Eq (9), we obtain the differential form of our model of the conservation and continuity of the electromagnetic power (energy flow rate) density:

$$\nabla \cdot (\mathbf{E} \times \mathbf{H}^*) = -\varepsilon'\mathbf{E} \cdot \frac{\partial \mathbf{E}^*}{\partial t} - \mu'\mathbf{H}^* \cdot \frac{\partial \mathbf{H}}{\partial t} - \sigma'\mathbf{E} \cdot \mathbf{E}^* - i\varepsilon''\mathbf{E} \cdot \frac{\partial \mathbf{E}^*}{\partial t} + i\mu''\mathbf{H}^* \cdot \frac{\partial \mathbf{H}}{\partial t} \qquad (12)$$

Eq (12) includes rich information of the electromagnetic fields. On the left side of the equation, the term is the divergence of the complex Poynting vector, and it indicates the electromagnetic (real and imaginary) transferring power (flux) densities; on the right side of the equation, the terms cover the (real) Ohmic, dielectric and magnetic dissipating power densities as well as the (imaginary) electric and magnetic storing power densities.

We think: another physics meaning of Eq (12) is, for electromagnetic fields, a variation of any energy density in time domain could produce a variation of another energy density in time domain and (or) a variation of the transferring power (flux) density in space domain, vice versa.

Based on Eq (12) and Gauss's flux theorem, by respectively integrating the equality of one-half the real (Re) and imaginary (Im) parts in space domain, we can respectively obtain our modeling equations of the time-average transferring (the left side term on Eq (13)), dissipating (the right side term on Eq (13)) and storing electromagnetic powers (Eq 14) in the closed surface S that bounds the volume V, they are respectively:

$$\oint_S \frac{1}{2}\mathrm{Re}(\mathbf{E}\times\mathbf{H}^*)\cdot \mathrm{ds} = \int_V \frac{1}{2}\mathrm{Re}\left(-\varepsilon'\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} - \mu'\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t} - \sigma'\mathbf{E}\cdot\mathbf{E}^* - \mathrm{i}\varepsilon''\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} + \mathrm{i}\mu''\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t}\right)\mathrm{dv} \quad (13)$$

$$\oint_S \frac{1}{2}\mathrm{Im}(\mathbf{E}\times\mathbf{H}^*)\cdot \mathrm{ds} = \int_V \frac{1}{2}\mathrm{Im}\left(-\varepsilon'\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} - \mu'\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t} - \sigma'\mathbf{E}\cdot\mathbf{E}^* - \mathrm{i}\varepsilon''\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} + \mathrm{i}\mu''\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t}\right)\mathrm{dv} \quad (14)$$

We think: a spatial integral of the complex Poynting vector, Eq (12), i.e., the sum of the two terms on left sides of Eqs (13) and (14) is equivalent to a complex power (apparent power) in equivalent circuits (without any ECS); the terms on right sides of Eqs (13) and (14) are respectively equivalent to active (average, real and consumed) and reactive (quadrature) powers in equivalent circuits [17, 18]. Therefore, of a right power triangle, the hypotenuse side is the spatial integral of the complex Poynting vector, while the two legs are the dissipating and storing powers.

Generally, biological cells have many ECSs. When an ECS is present in our considered regions, we extend our modeling Eq (12) to the following,

$$\mathbf{J}_\mathbf{g}^*\cdot\mathbf{E} = -\varepsilon'\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} - \mu'\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t} - \sigma'\mathbf{E}\cdot\mathbf{E}^* - \mathrm{i}\varepsilon''\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} + \mathrm{i}\mu''\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t} - \nabla\cdot(\mathbf{E}\times\mathbf{H}^*) \quad (15)$$

Where, $\mathbf{J}_\mathbf{g}^*$ represents an ECS generated current density [2]; the others denote the same as the above.

Therefore, based on Eq (15) and Gauss's flux theorem, we can obtain our extended modeling equation of the time-average real generating (the left-side of Eq (16)), transferring-out (the last term on the right side of Eq (16)) and dissipating (other terms on the right side of Eq (16)) electromagnetic powers, in the closed surface S that bounds the volume V:

$$\int_V \frac{1}{2}\mathrm{Re}\left(\mathbf{J}_\mathbf{g}^*\cdot\mathbf{E}\right)\mathrm{dv} = \int_V \frac{1}{2}\mathrm{Re}\left(-\varepsilon'\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} - \mu'\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t} - \sigma'\mathbf{E}\cdot\mathbf{E}^* - \mathrm{i}\varepsilon''\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} + \mathrm{i}\mu''\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t}\right)\mathrm{dv} - \oint_S \frac{1}{2}\mathrm{Re}(\mathbf{E}\times\mathbf{H}^*)\cdot\mathrm{ds} \quad (16)$$

In the same way, we can obtain our extended modeling equation of the time-average imaginary generating (the left-side of Eq (17)), transferring-in (the last term on the right side of Eq (17)) and storing (other terms on the right side of Eq (17)) electromagnetic powers, in the closed surface S that bounds the volume V:

$$\int_V \frac{1}{2}\mathrm{Im}\left(\mathbf{J}_\mathbf{g}^*\cdot\mathbf{E}\right)\mathrm{dv} = \int_V \frac{1}{2}\mathrm{Im}\left(-\varepsilon'\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} - \mu'\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t} - \sigma'\mathbf{E}\cdot\mathbf{E}^* - \mathrm{i}\varepsilon''\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} + \mathrm{i}\mu''\mathbf{H}^*\cdot\frac{\partial \mathbf{H}}{\partial t}\right)\mathrm{dv} - \oint_S \frac{1}{2}\mathrm{Im}(\mathbf{E}\times\mathbf{H}^*)\cdot\mathrm{ds} \quad (17)$$

Therefore, of a right triangle of time-average power with an ECS, the hypotenuse is the current source power, while one leg is the sum of the dissipating and real transferring-out powers, another leg is the sum of the storing and imaginary transferring-in powers.

3.3 Electromagnetic models of biochemical transferring, working, and memorizing powers

A biologic system (especially for a neuron or synapse) is different from a mechanic system: the former can think with dissipating powers as well as can transfer and store powers; the later cannot think but can transfer, dissipate, and store powers. Therefore, for a biochemical system without any ECS, our models are: the spatial integrals of the complex Poynting vector, using Eq (12) and Gauss's flux theorem, are respectively real and imaginary transferring powers that respectively provide the (real, Eq (13)) working and (imaginary, Eq (14)) memorizing powers, the working includes the thinking, moving and heating (e.g., to maintain a constant animal body temperature); for a biochemical system with an ECS, our models are: the spatial integrals of the ECS power densities, by using Eq (15) and Gauss's flux theorem, are respectively real and imaginary ECS powers that respectively provide the real working and transferring-out powers (Eq (16)) as well as the imaginary memorizing and transferring-in powers (Eq (17)) [9, 10, 12]; a variation of any energy density in time domain can produce a variation of an another energy density in time domain and (or) a variation of Poynting vector in space domain, vice versa (Eqs. (12) and (15)).

3.4 Electromagnetic models of biochemical working, memorizing, and transferring factors

For a biochemical electromagnetic (half or open) oscillator or resonator (e.g., a neuron, myocardium, or synapse), we propose four modeling factors (efficiencies): the first one is a working factor W that describes information and power processing efficiency and covers thinking, moving and (or) heating. For a biochemical system without any ECS, based on Eqs (12 – 14), the working factor is,

W_0 = (Working Powers)/|Transferring Powers| (18a)

i.e., $$W_0 = \frac{\oint_S \frac{1}{2}\mathrm{Re}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\oint_S \frac{1}{2}(\mathbf{E}\times\mathbf{H}^*)\cdot ds\right|} \quad (18b)$$

and for a biochemical system with ECS, based on Eqs (15 – 17), the working factor is,

W_s = [Re (Source Powers) – Transferring-out Power]/|Source Powers| (19a)

i.e., $$W_s = \frac{\int_V \frac{1}{2}\mathrm{Re}(\mathbf{J_g^*}\cdot\mathbf{E})dv + \oint_S \frac{1}{2}\mathrm{Re}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\int_V \frac{1}{2}(\mathbf{J_g^*}\cdot\mathbf{E})dv\right|} \quad (19b)$$

Usually, the working factor W can be positive only. The larger the factor, the higher the working efficiency [9, 10, 12].

The second one is a memorizing factor $\mathcal{M}$ that describes information and power storing efficiency. For a biochemical system without any ECS, based on Eqs (12 - 14), it is,

$\mathcal{M}_0$ = (Memorizing Powers)/|Transferring Powers| (20a)

i.e., $$\mathcal{M}_0 = \frac{\oint_S \frac{1}{2}\mathrm{Im}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\oint_S \frac{1}{2}(\mathbf{E}\times\mathbf{H}^*)\cdot ds\right|} \quad (20b)$$

and for a biochemical system with ECS, based on Eqs (15 - 17), it is,

$\mathcal{M}_s$ = [Im (Source Powers) – Transferring-in Power]/|Source Powers| (21a)

i.e., $$\mathcal{M}_s = \frac{\int_V \frac{1}{2}\mathrm{Im}(\mathbf{J_g^*}\cdot\mathbf{E})dv + \oint_S \frac{1}{2}\mathrm{Im}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\int_V \frac{1}{2}(\mathbf{J_g^*}\cdot\mathbf{E})dv\right|} \quad (21b)$$

Usually, the memorizing factor $\mathcal{M}$ can be positive or negative. Our model is: when $\mathcal{M} > 0$, the biochemic system is gaining memory and power; when $\mathcal{M} < 0$, the biochemic system is losing memory and power. The larger the factor, the higher the memory efficiency [9, 10, 12].

The third one is a transferring-out factor that describes the real (average) information and power transferring-out efficiency, for a biochemical system with ECS, based on Eqs (15 - 17), it is,

$\Upsilon_{s,o}$ = [Transferring-out Powers)]/|Transferring Powers| (22a)

i.e., $$\Upsilon_{s,o} = \frac{-\oint_S \frac{1}{2}\mathrm{Re}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\oint_S \frac{1}{2}(\mathbf{E}\times\mathbf{H}^*)\cdot ds\right|} \quad (22b)$$

The transferring-out factor is, in principle, like the maximum power transfer efficiency from one region to another region in classic circuits. Its maximum value is 50% [18].

The fourth one is a transferring-in factor that describes the imaginary information and power transferring-in efficiency, for a biochemical system with ECS, based on Eqs (15 - 17), it is,

$\Upsilon_{s,i}$ = [Transferring-in Powers)]/|Transferring Powers| (23a)

i.e., $$\Upsilon_{s,i} = \frac{-\oint_S \frac{1}{2}\mathrm{Im}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\oint_S \frac{1}{2}(\mathbf{E}\times\mathbf{H}^*)\cdot ds\right|} \quad (23b)$$

Usually, the transferring factors can be positive or negative. Our model is: when $\mathbf{Ţ} > 0$, the transferring direction is the same as the reference direction; when $\mathbf{Ţ} < 0$, the transferring direction is opposite to the reference direction. The larger the (absolute) factor, the high the transferring efficiency [9, 10, 12].

Based on Eqs (15, 19, 21, 22, 23) and the right triangle of electromagnetic powers, at a given ECS power, usually, the higher the working factor, the lower the memorizing and (or) transferring factors, vice versa. We believe, the optimum method to enhance the working, memorizing, and transferring powers is to increase the ECS powers, i.e., the apparent powers in equivalent circuits.

3.5 Electromagnetic models of biochemical quality factors

A quality factor is defined as a ratio of stored powers over dissipated powers in electromagnetics [1, 4]. For a biochemical electromagnetic (half or open) oscillator or resonator (e.g., a neuron, myocardium, or synapse), if there is not any ECS, based on Eqs (12 – 14), our model of quality factor is,

$$Q_0 = (\text{Memorizing Powers})/|\text{Working Powers}| \quad (24a)$$

i.e., $$Q_0 = \frac{\oint_S \frac{1}{2}\mathrm{Im}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\oint_S \frac{1}{2}\mathrm{Re}(\mathbf{E}\times\mathbf{H}^*)\cdot ds\right|} \quad (24b)$$

Eqs (24) are consistent with the quality factor of classic passive resonators in physics [4].

If a biochemical system has an ECS, based on Eqs (15 – 17), our model of quality factor is,

$$Q_s = (\text{Memorizing Powers})/|\text{Working Powers}| \quad (25a)$$

i.e., $$Q_s = \frac{\int_V \frac{1}{2}\mathrm{Im}(\mathbf{J_g^*}\cdot\mathbf{E})dv+\oint_S \frac{1}{2}\mathrm{Im}(\mathbf{E}\times\mathbf{H}^*)\cdot ds}{\left|\int_V \frac{1}{2}\mathrm{Re}(\mathbf{J_g^*}\cdot\mathbf{E})dv+\oint_S \frac{1}{2}\mathrm{Re}(\mathbf{E}\times\mathbf{H}^*)\cdot ds\right|} \quad (25b)$$

Eqs (25) are our extended quality factor based on Eqs (24).

3.6 Extending our models to a system with multiple same neurons

Theoretically, we can extend our modeling equations in this paper to a system with multiple same neurons by sums of all the same neurons (j = 1, 2, … J) and synapses (k = 0 (neuron itself), 1, 2, … K) in the system (e.g., an organ) to obtain a total transferring, working, and memorizing powers and correspondent factors.

4 DISCUSSIONS

4.1 The first and second Laws of thermodynamics and our models

A life is an open system, an open system exchanges information, energies and matters with its environments [12]. Of open systems: our modeling equations (12) and (15) are equivalent to a differential form of the First Law of thermodynamics: conservation of energy; in accordance with the First Law of thermodynamics, our modeling equations (18) and (19) are equivalent to Carnot's theorem of the efficiency of a heat engine; after dividing our modeling equations (13), (14), (16) and (17) by a (e.g., an animal body) constant Kelvin temperature T_c (K), we obtain the entropy flow rate expressions of our modelling equations, and the entropy expressions are equivalent to integral forms of the Second Law of thermodynamics: The sum of the entropy changes of a system and its exterior can never decrease [20].

4.2 Prigogine's theories of dissipative structures and our models

Ilya Prigogine discovered: dissipation of energy into chemical systems could result in the emergence of new structures, i.e., dissipative structures, due to entropy fluctuations, dissipative processes, and internal self-reorganization. [19 - 21]

In this study, the integral of the complex Poynting's vector (transferring-in) and working (dissipating) powers in our considered biochemical systems are equivalent to Prigogine's dissipation of energy into chemical systems; the memorizing powers in our modelling equations are related to Prigogine's dissipative structures; electromagnetic fields in our models are equivalent to Prigogine's organized nonequilibrium states; electromagnetic powers / T_c(K), i.e., temporal variations of energies / T_c(K), of our models are equivalent to Prigogine's entropy fluctuations.

Therefore, our modeling equations in this study are (almost) consistent with the theories of Prigogine's dissipative structures.

4.3 Conditions of stabilities for our models' nonequilibrium states using Lyapunov's theory

Our models in this investigation describe how biological cells (especially neurons) work and memorize as well as transfer (energies) powers, the differential equations of our models mathematically elucidate nonequilibrium states of nonlinear oscillations.

A very general criterion for stability of a state was formulated by Lyapunov [20, 24]. The condition for the stability of both equilibrium and nonequilibrium state conditions using Lyapunov's theory is [20]: the time derivative for the second variation of entropy is greater than zero.

After dividing our modeling equations (13), (14), (16) and (17) by a (e.g., an animal body) constant Kelvin temperature T_c (K), we obtain our four models of entropy flow rate expressions of the thermodynamics. Therefore, if the second variations of the four entropy expressions are respectively greater than zero, all our models are theoretically stable. Usually, the biological cells are stable indeed.

4.4 Asymptotic stabilities of our models

Based on Eqs (12, 13, 15, 16), we know: the electromagnetic dissipations are quadratic functions of the electromagnetic fields; they play roles in reducing or (limiting) charged object's motion speeds and making their movements to reach stabilities (stable points) or constant velocities; additionally, the dissipations may have the effect of bringing the systems back to the equilibrium [25] or organized configurations [19], starting from small enough perturbations, either in finite time or asymptotically for $t \rightarrow +\infty$, these are the cases of asymptotic stabilities. [25].

4.5 Complex forms of Poynting vector (divergence), permittivity and permeability

In this study, we must use complex (conjugate) forms of Poynting vector (divergence), permittivity and permeability, to obtain the dielectric and magnetic dissipating power densities as well as the Ohmic (conductive) dissipating and electric and magnetic storing power densities.

Mathematically, coordinates with the real axes only are often not complete in theoretical physics; complex numbers include more information than real numbers; complex numbers are at least two dimensional; one is the real and another one is imaginary; the real and imaginary axes are perpendicular (90^o) each other. In theories of waves, oscillations or vibrations, the complex coordinates play important roles. Especially, in microscopic space – time, e.g., quantum mechanics and its wave (Schrodinger: energy or probability) equations, the imaginary axis cannot be neglected in the theory. We must use complex numbers (X_c) with both real (X_r) and imaginary (X_i) parts to represent the stereoscopic waves for the completeness, because the energy or probability densities are involved in $|X_c|^2 = X_c X_c^*$, where the complex is $X_c = X_r + \sqrt{-1}\, X_i$ and the complex conjugate is $X_c^* = X_r - \sqrt{-1}\, X_i$ [11].

4.6 The gravitational force is neglected in usual biological systems

Electromagnetic forces between particles are generally about 10^{33} times stronger than that of the gravitational [5, 12]. Therefore, we usually neglect the gravitational force.

Gravitational field, power, and energy (densities) for particles are mathematically like the electromagnetic. We can obtain our complete models after adding the correspondent gravitational terms [12].

4.7 Futural studies

Futural studies might be focused on how to efficiently enhance human abilities (powers) of thinking, memorizing, and transferring information.

5 CONCLUSION

We believe our models will be helpful to prevent and (or) cure diseases of thinking and memorizing as well as to understand how neurons process, store and transfer information and powers, because in physics and (or) mathematics, our models are almost consistent with the first and second laws of thermodynamics, theories of Prigogine's dissipative structures and Lyapunov's stabilities.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflict of interest.

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