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Dynamics of information-storing biomagnetites in bio-quantum computing system

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ABSTRACT

Some of biomagnetites are capable of functioning in bio-quantum computers as information storage, while most biomagnetites are somewhat cursory. Dynamics of biomagnetites in the presence of an external sinusoidal magnetic field is investigated. From the time-dependent Hamiltonian that describes the mechanics of biomagnetites, we derived an adiabatic invariant which is a useful tool for analyzing dynamical properties of the system. The time behavior of the Hamiltonian and the mechanical energy of the biomagnetite element is illustrated and addressed.

Keywords: Biomagnetites, Adiabatic Invariant, Thermal Noise

Abbreviations: DNA- deoxyribonucleic acid.

1. INTRODUCTION

Organic molecules and free radicals in living organisms exhibit diverse magnetic characteristics primarily due to biomagnetites. Biomagnetites are nanometer-sized intracellular crystals composed of Fe_3O_4 and are usually found in single-domain units (magnetosomes) enveloped by a membrane in a cell. Unique characteristics of biomagnetites has opened potential applications in nano- and biotechnological science. Plenty of models and interpretations for the effects of weakly magnetized biomagnetites on living cells are proposed. They are quantum oscillator models, quantum interference between bound ions and electrons, magnetosensitive free-radicals, parametric resonance, coherent quantum excitations, eddy current effects, and cyclotron and/or stochastic resonance (Binhi, 1999; Bokkon and Salari, 2010). In particular, it is recently raised that the process of information storage in living systems might take place in biomagnetites rather than in DNA, meanwhile manifestation of the fixed information occurs at the level of DNA (Bokkon and Salari, 2010). For this reason, some of biomagnetites are expected to be capable of functioning in computers as information storage while most biomagnetites are somewhat cursory (Bokkon and Salari, 2010; Lang et al., 2007). Recently, the function of biomagnetites as an information storage has been a topic of active research (Banaclocha et al., 2010; Bokkon and Salari, 2010; Størmer et al., 2011).

For understanding the mechanism of the action of biomagnetites, the development of their underlying mechanics may be necessary. Dynamics of information-storing biomagnetites that can be possibly applied in bio-quantum computing system will be investigated in this paper. The effects of external magnetic fields on biomagnetites will be analyzed using fundamental mechanics for describing the system, such as adiabatic invariant theory. By analyzing adiabatic properties of angular motion of the biomagnetite in the presence of a sinusoidal magnetic field, the time behavior of the corresponding Hamiltonian and the mechanical energy of the biomagnetite element will be investigated.

2. MECHANICAL DESCRIPTION OF BIOMAGNETITES

If we exert low-frequency magnetic fields in a biomagnetite, a torque would be induced upon it. This may results in important consequences which act to rotate the whole cell via forces applied in the individual magnetosomes. Biological effects are generated through such rotation.

Let the external magnetic field be a sinusoidal one which can be represented as

$$B(t) = B_0 \cos(\omega t + \alpha). \tag{1}$$

Under this field, a biomagnetite which have a magnetic moment μ and a moment of inertia I suffers a torque. The oscillatory angular motion of the biomagnetite element due to such torque follows a linear equation of the form (Adair, 1994; Bokkon and Salari, 2010)

$$\ddot{\theta} + \frac{\gamma}{I}\dot{\theta} + \omega_0^2 \theta = \frac{\mu}{I} B(t) \cos\phi \sin\psi + \xi(t), \tag{2}$$

where $\omega_0 = (\kappa / I)^{1/2}$, γ and κ are scalar coefficients, ψ is the angle between $B(t)$ and μ, ϕ is the angle between the direction of the applied torque and the final acceleration, $\xi(t)$ is the effects of thermal agitation (thermal noise). The classical solution of Eq. (2) can be written as

$$\theta(t) = \theta_c(t) + \theta_p(t), \tag{3}$$

where $\theta_c(t)$ is a complementary function and $\theta_p(t)$ is a particular solution (Thornton and Marion, 2004). The solution $\theta_c(t)$ for the underdamped motion of biomagnetite is well known and it is given by

$$\theta_c(t) = \theta_{c,0} e^{-\gamma t/(2I)} \cos(\omega_1 t + \varphi), \tag{4}$$

where $\theta_{c,0}$ is a constant, $\omega_1 = [\omega_0^2 - \gamma^2/(4I^2)]^{1/2}$, and φ is an arbitrary phase.

On the other hand, it is not always possible to derive the solution $\theta_p(t)$. We can derive it only for some particular cases. For example, for $\xi(t) = 0$, $\theta_p(t)$ is given by

$$\theta_p(t) = \frac{\mu B_0 \cos\phi \sin\psi}{\sqrt{(\omega_0^2 - \omega^2)^2 I^2 + \gamma^2 \omega^2}} \cos(\omega t + \alpha - \delta), \tag{5}$$

where

$$¢ = \tan^{-1}\left(\frac{\mu}{(\mu_0^2 - \mu^2)I}\right). \qquad (6)$$

This is a sinusoidal function which has a steady amplitude. Notice that the frequency of the oscillation of $¯_p(t)$ is the same as the frequency of the driving magnetic field, μ.

3. ANALYSIS OF DYNAMICAL PROPERTIES

Dynamical properties of the magnetite in the presence of $B(t)$ will be investigated in this section. From Eq. (2), we can easily show that the Hamiltonian of the system is given by

$$H = e^{-\ t/I}\frac{p^2}{2I} + \frac{1}{2}e^{\ t/I}[©¯^2 - 2\Pi(t)¯], \qquad (7)$$

where $p_{¯} = Ie^{\ t/I}\dot{¯}$ and $\Pi(t)$ is a time function of the form

$$\Pi(t) = «B(t)\cos ¨\ \sin ¶ + ¡(t)I. \qquad (8)$$

For conventional systems whose Hamiltonian is not a function of time, the mechanical energy can be derived from the Hamiltonian. However, for the case that the Hamiltonian is represented in terms of t such as the dissipative system, the mechanical energy is not always the same as the Hamiltonian (Marchiolli and Mizrahi, 1997; Yeon et al, 1987). Because   in Eq. (7) plays the role of a dissipation term, the energy of the system is different from the Hamiltonian. For this system, the relation between the corresponding mechanical energy and the Hamiltonian is given by (Yeon et al, 1987)

$$E = He^{-\ t/I}. \qquad (9)$$

It may be possible to know the complete classical solution $¯(t)$ of the system for simple particular cases. For instance, as shown in the previous section, Eq. (3) with Eqs. (4) and (5) is the classical solution for the case $¡(t) = 0$. By inserting that solution and its time derivative into Eq. (7), we know the time behavior of the Hamiltonian and the corresponding mechanical energy. However, for general cases, we are unable to know such informations from the classical solution because $¯(t)$ is unknown in that cases. Hence we should seek other method in order to find the time behavior of dynamical variables in a general case. Adiabatic invariant method is a useful tool for investigating the characteristics of general dynamical systems, including such time behaviors. However, this method is valid only when the parameters of the system vary sufficiently slowly.

Now, we derive an adiabatic invariant by manipulating the Hamiltonian of the system. For such purpose, we express Eq. (7) into another form as

$$\frac{p_{¯}^2}{a^2(t)} + \frac{[¯ - ¯_0(t)]^2}{b^2(t)} = 1, \qquad (10)$$

where

$$¯_0(t) = \frac{1}{©}\Pi(t), \qquad (11)$$

$$a^2(t) = 2Ie^{\ t/I}\left(H + \frac{1}{2©}e^{\ t/I}\Pi^2(t)\right), \qquad (12)$$

$$b^2(t) = \frac{2}{©}\left(He^{-\ t/I} + \frac{1}{2©}\Pi^2(t)\right). \qquad (13)$$

We suppose that the system undergos an adiabatic change for convenience, which corresponds to a slow variation of its parameters. Then, we can analyze the system using adiabatic invariants. In general, an adiabatic invariant J is constructed from

$$J = \oint p_{¯}\,d¯ = ®\,a(t)b(t). \qquad (14)$$

This stays constant during the slow change of time functions given in Eq. (2). If we use Eqs. (12) and (13), the above equation becomes

$$J = \frac{2\circledR}{\mu_0}\left(H(t) + \frac{1}{2\copyright} e^{\ t/I}\Pi^2(t) \right). \quad (15)$$

Regarding a useful property of the adiabatic invariant, which is the conservation of its quantity during a time evolution of the system, we put

$$J(t) = J(0). \quad (16)$$

Then, by inserting Eq. (15) into Eq. (16), we confirm that the time evolution of the Hamiltonian is represented as

$$H(t) = H(0) - \frac{1}{2\copyright}\left(e^{\ t/I}\Pi^2(t) - \Pi^2(0) \right). \quad (17)$$

This is illustrated in Fig. 1 under the assumption, for convenience, that the thermal noise $\text{¡}(t)$ is a high-frequency sine function of t, i.e.,

$$\text{¡}(t) = \text{¡}_0 \sin(50t), \quad (18)$$

for several numerical values of the amplitude ¡_0. As you can see, the time variation of $H(t)$ is somewhat complicated. There is microscopic fluctuation of the Hamiltonian, as well as macroscopic fluctuation. Such microscopic fluctuation appears in the form of a random change of the Hamiltonian in actual systems, which is originated from the thermal agitation. It is known that thermal agitation is a source of noise, where the understanding of the behavior of a noise-driven system is a difficult problem in mathematical point of view (Johnson, 1927; McClintock, 1999). From the comparison of Fig. 1(b), which corresponds to high thermal agitation, with Fig. 1(a), we see that the amplitude of such change increases as thermal effects grow. By the way, by comparing the three lines in Fig. 1(a) [or 1(b)], we can conclude that the macroscopic fluctuation of the Hamiltonian grows as $B(t)$ increases.

Hence, by considering Eqs. (9) and (17), we can represent the time evolution of the mechanical energy as

$$E(t) = e^{-\ t/I}\left[E(0) - \frac{1}{2\copyright}\left(e^{\ t/I}\Pi^2(t) - \Pi^2(0) \right) \right]. \quad (19)$$

Figure 2 is the illustration of the time evolution of this energy. Because the envelope of the graph for the oscillatory energy in this figure decreases with time, we can conclude that the mechanical energy dissipates.

For a particular case where $B(t)$=0 and $\text{¡}(t) = 0$, Eq. (19) reduces to

$$E(t) = e^{-\ t/I}E(0). \quad (20)$$

Thence, when the forces originated from the external magnetic field and the thermal noise are removed, the energy dissipates purely exponential way as expected.

4. CONCLUSION

The dynamical properties of angular motion of information-storing biomagnetites under external magnetic field $B(t)$ have been investigated through the adiabatic invariant method. The time evolution of both the Hamiltonian and the mechanical energy was addressed through their illustrations. For the case of time-varying dissipative systems like this, the Hamiltonian and the mechanical energy are different from each other. The results, Eqs. (17) and (19), are approximated ones valid only for the cases where the parameters of the system undergo adiabatic changes. There are no known methods to find exact time behavior of such dynamical variables without exact knowledge of the classical solution $\bar{}(t)$ for general time-dependent Hamiltonian systems.

Not only macroscopic but also microscopic oscillations (fluctuations) of both the Hamiltonian and the mechanical energy appeared in the graphs of Figs. 1 and 2, which are plotted under the assumption that thermal noise $\text{¡}(t)$ is an high frequency sine function of t for convenience. The macroscopic oscillation is originated from the effects of $B(t)$, while the microscopic oscillation from the effects of As the scale of $B(t)$ increases, the amplitude of macroscopic

¡ (t).

oscillation for both $H(t)$ and $E(t)$ becomes high. The envelope of the macroscopic oscillation of the mechanical energy decreases with time according to the dissipation of the energy. Although the effects of thermal noise are appeared in the form of microscopic oscillation in $H(t)$ and $E(t)$ in our approximated analysis performed through the assumption given in Eq. (18), such effects may appear, in actual systems, in the form of random changes of $H(t)$ and $E(t)$. We see by comparing Fig. 1(a) with Fig. 1(b) that the random change of the Hamiltonian is large when the amplitude of ¡ (t) is high. Our mechanical analysis for angular motion of the biomagnetite element may contribute to understanding the dynamical properties of the information-storing biomagnetites.

DISCLOSURE STATEMENT

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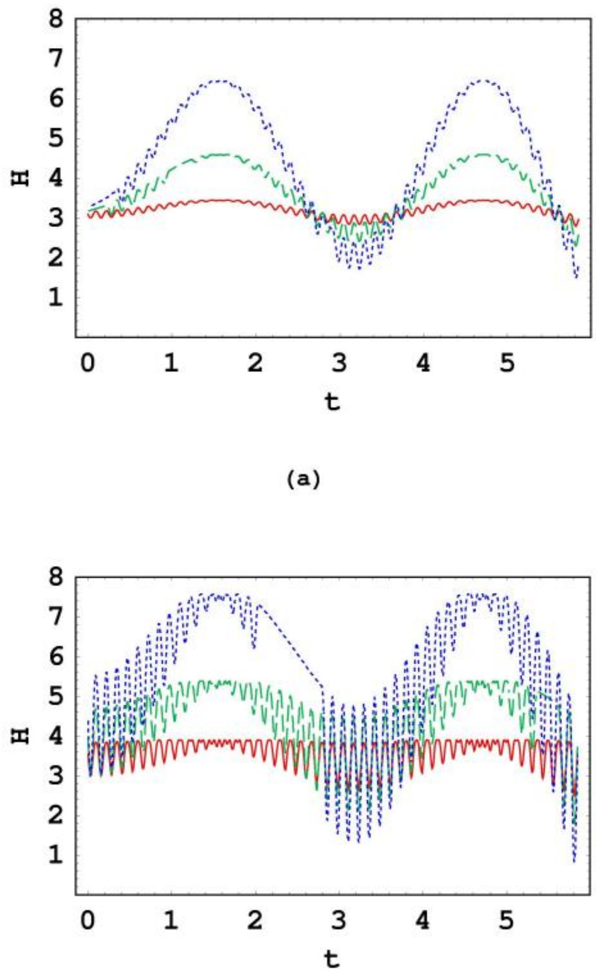

(a)

(b)

Figure 1

Time evolution of the Hamiltonian given in Eq. (17) for ¡ $(t) =$ ¡ $_0 \sin(50t)$ where ¡ $_0 = 0.1$ for (a) and ¡ $_0 = 0.5$ for (b). The value of B_0 is 1 for the solid red line, 2 for the long dashed green line, and 3 for the short dashed blue line. We have used © $= 1$, ¤ $= 0$, $= 0.1$, $H(0) = 3$, $I = 1$, ¨ $= 0$, ¶ $= 1$, « $= 1$, and µ $= 1$.

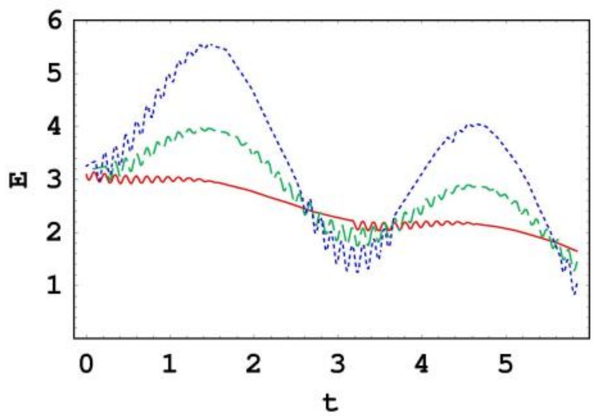

Figure 2

Time evolution of the mechanical energy given in Eq. (19) for ¡ $(t) =$ ¡ $_0 \sin(50t)$ where ¡ $_0 = 0.1$. The value of B_0 is 1 for the solid red line, 2 for the long dashed green line, and 3 for the short dashed blue line. We have used © $= 1$, ¤ $= 0$, $= 0.1$, $E(0) = 3$, $I = 1$, ¨ $= 0$, ¶ $= 1$, « $= 1$, and µ $= 1$.

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