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The influence of a static magnetic field on the behavior of a quantum mechanical model of matter

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ABSTRACT

The paper presents an experimental measurement of a material inserted in various types of magnetic field. The related model accepts the time component of an electromagnetic field from the perspective of the properties of matter. Relatively moving systems were derived and tested (Fiala et al., 2011 [1]), and the influence of the motion on a superposed electromagnetic field was proved to exist already at relative motion speeds. In micro- and nanoscopic objects, such as the basic elements of matter, the effect of an external magnetic field on the growth and behavior of the matter system needs to be evaluated. We tested the model based on electromagnetic field description via Maxwell's equations, and we also extended the monitored quantities to include various flux densities. Experiments were conducted with growth properties of simple biological samples in pre-set external magnetic fields.

1. Introduction

The authors describe and verify the growth characteristics of simple tissue structures in relation to a present external magnetic field (Fiala et al., 2011 [1]); the results of the research are to clarify the effects of magnetic (geomagnetic) field changes on such cultures. Although the first biological experiments showed that, in the given sense, magnetic fields do exhibit certain statistically significant influence, the question remained of what tools and model parameters are applicable for the description of a complex system embodied in, for example, even a very simple tissue structure. The referenced papers present various approaches to and aims of the investigation of an external magnetic field on the surrounding environment. Roda [2] described the very specific influence of a stationary magnetic (50 μT) and an electromagnetic (6 μT, 50 Hz) field on animal tissues as regards their ability to stimulate or restrain antioxidative enzymes. The effects of stationary gradient magnetic fields (4.3 T/m) on the growth of eukaryotic organisms are discussed in article [3]; the related experiments showed that although the speed and growth phase of the exposed population of Paramecium caudatum do not differ significantly from those observed in check populations, a major negative decrease (by 10.5–12.2%) occurs in both the time necessary for the maximum growth of the organism and the number of individuals in a colony (10.2–15.1%). Paper [2] presents the conclusions obtained from experiments targeting the influence of a pulse magnetic field (10 μT and 100 Hz, with the duty cycle of 2:1 and period of 1 s) on fertilized eggs of domestic fowl (Gallus domesticus). After 15 days of the experimental cycle, the exposed embryos exhibited a higher somatic weight and a more advanced stage of development than their control counterparts; at 21 days into the experiment, the somatic weight and stage of development were lower in the exposed embryos than in the control ones. The difference is not discernible in embryos that have been exposed to a magnetic field with harmonic waveform of the frequency of 50 Hz. The experiment [4] proposes that the action of a magnetic field (480 mT) on samples of maize (*Zea mays* L.) sown in a substrate increases the growability, growth in percent, and weight of the dry sample; however, under action of the magnetic field, the growth of the given type of seed differs depending on its genetic variability.

According to an earlier study [5], a strong external magnetic field introduces a basic anisotropy into incompressible magnetohydrodynamic turbulence. The conclusion is reached that the turbulent spectrum splits into two parts: an essentially two-dimensional spectrum with both the velocity field and magnetic fluctuations perpendicular to the magnetic field, and a generally weaker and more nearly isotropic spectrum of Alfven waves. The discussed paper [5] comprises an elementary evaluation of the properties of a dynamic environment; the influence of an external magnetic field on a biological system including nanoparticles is

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then analyzed, together with the activation of such a system, in article [6]. In this context, let us note that activated platelets play a pivotal role in cardiovascular diseases such as atherothrombosis. Thus, strategies enabling activated platelet molecular imaging are of great interest; herein, a chemical protocol was investigated for coating superparamagnetic iron oxide nanoparticles with low molecular weight fucoidan, a ligand of P-selectin expressed on the surface of activated platelets. The physico-chemical characterization of the obtained product demonstrated successful fucoidan coating and its potential as a T2 MRI contrast agent. The specificity and the strength of the interaction between fucoidan-coated iron oxide nanoparticles and human activated platelets was demonstrated by flow cytometry. Micromagnetophoresis experiments revealed that platelets experience magnetically induced motion in the presence of a magnetic field gradient created by a micromagnet. Altogether, these results indicate that superparamagnetic iron oxide nanoparticles coated with low molecular weight fucoidan may represent a promising molecular imaging tool for activated platelets in investigating human diseases.

The results of the research into the influence of external magnetic fields are presented within a large number of sources, such as those that discuss the modeling of matter based on quantum theory [7]. The referenced article investigates the thermal entanglement in the two-qubit Heisenberg XY model with a nonuniform magnetic field, and the authors find that the entanglement and the critical temperature TC may be enhanced under a nonuniform magnetic field. Paper [8] then attempts to clarify the mechanism of the influence of an external magnetic field on radical-pair (RP) recombination from the perspective of a chemical model for the description of the sample properties. Magnetic field effects on the rate of RP recombination are the most widely understood mechanism by which magnetic fields interact with biological systems. However, the health-related relevance of this mechanism of magnetic field sensitivity is uncertain because the best-known effects only become significant at moderate magnetic flux densities above 1–10 mT. The authors of the study also summarize the theory of magnetic field effects on radical pair recombination and discuss the results obtained by investigating the photosynthetic reaction center and enzymes with RP intermediates.

Similarly to our previous experiments [9], we tested the proposed numerical model and measured the material heating speed; further, a method was designed for accurate verification of heating speed changes depending on the external magnetic field. This paper also proposes a very detailed analysis of the influence of a magnetic field upon inanimate objects.

Within the presented experiment, we measured the temperature change of a copper sensor in a stationary homogeneous and gradient magnetic field. Up to 10 times, the given sample was cooled down to the nitrogen boiling point ($-195.80\,^{\circ}\mathrm{C}$ to 77.35 K); the sample was then removed at the pre-selected time and subsequently heated in another area to the temperature of $-20\,^{\circ}\mathrm{C}$. Using the measuring apparatus and 3 temperature sensors (1 sensor measuring the temperature of the sample and 2 others to measure the ambient temperature), we recorded the temperature change in the sample and the required heating time. This experiment was repeated with four magnetic fields.

2. Model: the electromagnetic field and particles

For a model with distributed parameters of the electromagnetic field, it is possible to use partial differential equations based on electromagnetic field theory to formulate a coupled model with concentrated parameters (in our case, particles) [9]. The details of the model are analyzed in this paper. The forces acting on a moving electric charge in the electromagnetic field can be expressed by means of the formula

$$f_{\mathrm{e}} = \rho(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}) \quad \text{in } \Omega, \tag{1}$$

where $\boldsymbol{B}$ is the magnetic flux density vector in the space of a moving electrically charged particle with the volume density ρ, v is the mean velocity of the particle, $\boldsymbol{v} = \mathrm{d}s/\mathrm{d}t$, s is the position vector from the beginning of the coordinate system o, t is the time, $\boldsymbol{E}$ is the electric intensity vector, and Ω is the definition region of the independent variables and functions. The properties of the area Ω are described by the mutual relationship between the intensities and inductions as defined by

$$rot\boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t} + rot(\boldsymbol{v} \times \boldsymbol{B}),\ rot\boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t} + rot(\boldsymbol{v} \times \boldsymbol{D}) \tag{2}$$

$$div\ \boldsymbol{B} = 0,\ div\ \boldsymbol{D} = \rho,\ \Omega, \tag{3}$$

where $\boldsymbol{H}$ is the magnetic field intensity vector, $\boldsymbol{J}$ is the current density vector, and $\boldsymbol{D}$ is the electric flux density vector. The material relations for the macroscopic part of the model are represented by the formulas

$$\boldsymbol{B} = \mu_0\mu_r\boldsymbol{H},\ \boldsymbol{D} = \varepsilon_0\varepsilon_r\boldsymbol{E}, \tag{4}$$

where μ represents the quantity indexes of the permeabilities and permittivities, r denotes the quantity of the relative value, and 0 is the value of the quantity for vacuum. The relationship between the macroscopic and the microscopic (dynamics of particles in the electromagnetic field) parts of the model is described by the relations of force action on the individual electrically charged particles in the electromagnetic field, and the effect is respected of the movement of electrically charged particles on the surrounding electromagnetic field according to [9]:

$$\begin{aligned} rot\ \boldsymbol{E} &= -\frac{\partial \boldsymbol{B}}{\partial t} + rot(\boldsymbol{v} \times \boldsymbol{B}) \\ &\quad -\frac{1}{\gamma} rot\left(\rho\boldsymbol{v} + \mathrm{j}c\rho\boldsymbol{u}_t + \boldsymbol{J} + \frac{\gamma}{q_e}\left(\frac{m_e \mathrm{d}\boldsymbol{v}}{\mathrm{d}t} + l\boldsymbol{v} + k\int_t \boldsymbol{v}\mathrm{d}t\right)\right) \\ rot\ \boldsymbol{H} &= \gamma\boldsymbol{E} + \rho\boldsymbol{v} + \gamma(\boldsymbol{v} \times \boldsymbol{B}) + \frac{\gamma}{q_e}\left(\frac{m_e \mathrm{d}\boldsymbol{v}}{\mathrm{d}t} + l\boldsymbol{v} + k\int_t \boldsymbol{v}\mathrm{d}t\right) \\ &\quad + \mathrm{j}c\rho\boldsymbol{u}_t + \frac{\partial \boldsymbol{D}}{\partial t} + rot(\boldsymbol{v} \times \boldsymbol{D}). \end{aligned} \tag{5}$$

The coupling of both models is formulated using both Eq. (5) and the formula

$$\begin{aligned} &q_e(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}) + \frac{q_e}{\gamma}\left(\rho\boldsymbol{v} + \mathrm{j}c\rho\mathbf{u}_t - \frac{\partial(\varepsilon\boldsymbol{E})}{\partial t}\right) \\ &\quad = \frac{m_e \mathrm{d}\boldsymbol{v}}{\mathrm{d}t} + l\boldsymbol{v} + k\int_t \boldsymbol{v}\mathrm{d}t. \end{aligned} \tag{6}$$

The effect of the behavior of the macroscopic model describing matter via the (old) quantum mechanical model of elements of the system can be observed using the fluxes of the quantities. The known quantities are magnetic flux ϕ, current flux I, and electric flux having the magnitude q:

$$\phi = \iint_{\Gamma} \boldsymbol{B} \cdot d\boldsymbol{S}, \quad I = \iint_{\Gamma} \boldsymbol{J} \cdot d\boldsymbol{S}, \quad q = \iint_{\Gamma} \boldsymbol{D} \cdot d\boldsymbol{S}, \tag{7}$$

where S is the vector of the oriented boundary (in a 3D model of the plane), and Γ is the boundary of the area Ω, in which the flux is evaluated. If there is a moving element of the system in the model with a scale difference expressed in orders, it is easier to describe the state and effect of the superposed electromagnetic field by expressing the time flux density τ. The time flux can be different or inhomogeneous in parts of the area Ω; it is then possible to write