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POSSIBLE CAUSES OF CHANGE IN THE DIRECTION OF EARTH'S MAGNETIC FIELD

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Abstract: The study of the magnetic properties of materials have attracted the interest of scientists for ages. Knowing the magnetic properties of materials do their best possible use in industry and technology, as well as better understanding of some yet unexplained phenomena in nature related to the Earth's magnetic field. Several models that describe the given phenomenon are known, such as the domino model, two-dimensional Ising model and model of inversion magnetic Earth's field. In computer experiments whose results are presented in this paper, it is used a simplified two-dimensional Ising model, one version of the model related spins. Computer experiments (simulations) are made in the mathematical software Maple. It has been observed reversing the direction of magnetization in a small change of inhomogeneity energy interactions. Consideration of this issue could be of importance for the study of ferromagnetic material.
Keywords: Boltzmann distribution, Ising model, magnetization, inhomogeneity energy interaction, geomagnetic field.

1. INTRODUCTION

The Earth has reversed the polarity of its almost dipolar magnetic field many times in the past at irregular intervals [1, 2]. That is the most remarkable phenomena of geomagnetism. Geomagnetic filed polarity reversals have had drastic effects on the inner radiation belts, as well on the access Galactic Cosmic Rays and Solar Energetic Particles into the magnetosphere. The magnetic field of the Earth originates from dynamo action in the liquid outer core [3].

Numerical simulations of the geodynamo successfully reproduce many features of the magnetic filed of the Earth including stochastic reversals [4].

Many authors propose several models which are in relation with geomagnetic field. In this paper, we will summarize some of these models and propose one. First, we will consider domino model [5]. In this model, authors solved the equation of motion of a one – dimensional planar Heisenberg (or Vaks – Larkin) model consisting of a system of interacting macro – spins aligned along a ring. In this model, each spin has unit length and described by its angle with respect to the rotational axis. Also, the orientation of the spins can vary in time due to spin-spin interaction and random forcing. Direct numerical simulations of the geodynamo are computationally expensive, but these simulations show that reversals go along with a breaking of the north –south (equatorial) symmetry in the flow of the aligned fluid columns. The numerical simulations may follow a similar reversals statistics as the paleomagnetic record. Domino model is one – dimensional XZ model, also refer to as the plane rotator model.

One more model, which can be used for describing geomagnetic is an analytical approach based on Störmer's theory [6]. Störmer's theory was originally developed for a dipole magnetic distribution. Lemaire has been complemented that theory by adding a uniform interplanetary magnetic filed (F) to the magnetic dipole (M) [7].

Two – dimensional Ising systems can be used for simulating the reversals of the Earths magnetic field, too. In that model, each spin was supposed to be one ring current in the Earth dynamo and the magnetization was supposed to be proportional to the field intensity. The temperature was used as a tuning parameter [8].

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2. MODEL

Ising–like models have been used in molecular dynamics and statistical mechanics for describing, phase transitions in ferromagnetism, or for modeling spin glasses [9]. The Ising model is concerned with the physics of phase transition which occurs when a small change in parameter, such as temperature or pressure, causes large scale qualitative change in state of a system. One purpose of the Ising model is to explain how short-range interactions between molecules in a crystal give rise to long–range, correlative behavior. Coupled spin models of Ising type, where the individual spins can assume two scalar states +1 and -1 and interact with each other after certain rules, have also been suggested for describing geomagnetic polarity reversals and their statistic [8].

Ising–like models are often classified according to spatial dimensionality and number of components of spin vectors. Our model is simplified two – dimensional Ising model.

It is assumed that the magnetization is

$$M = \frac{\sum_i M_i e^{-E_i/kT}}{\sum_i e^{-E_i/kT}} \tag{1}$$

and M_i and E_i are given by

$$M_i = \frac{1}{N^2}\sum_{j,n} S_{i,j,n} \tag{2}$$

$$E_i = -\sum_{j,n}\left(\varepsilon_{j,n} S_{i,j,n} S_{i,j,n+1} + \varepsilon_{j,n} S_{i,j,n} S_{i,j+1.n}\right) \tag{3}$$

$$\varepsilon_{j,n} = \varepsilon\left[1 + \alpha \cdot rand(-1,1)_{j,n}\right] \tag{4}$$

where α is non-homogeneity eider variation coefficient and *rand* $(-1,\ 1)_{j,n}$ is random number between -1 and 1, classified as spin.

Number of atoms which are ion state with energy *E*i is given by Boltzmann distribution. The Boltzmann distribution is a probability distribution that gives the probability that a system will be in a certain state as a function of that state's energy and the temperature of the system. It is given as

$$p_i = \frac{e^{-\frac{\varepsilon_i}{kT}}}{\sum_{j=1}^{M} e^{-\frac{\varepsilon_j}{kT}}} \tag{5}$$

where p_i is the probability of state i, ε_i the energy of state i, *k* the Boltzmann constant, *T* the temperature of the system and *M* is the number of states accessible to the system.

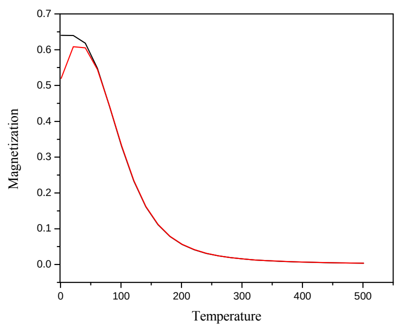
In the applied approximate model, random orientation of spins were generated in two dimensions, j and n. The value of spin (± 1), a lattice position j and n, and its contribution to the magnetization is calculated by averaging, i.e., divided into N^2. In this way, it takes into consideration the current average value of the magnetization. Averaging can serve to reduce the impact of randomly generated spins configuration, and thus reduce the error.

The program that is used in those experiments does not match the original Ising model, which is very far from reality, too, but makes it possible to obtain meaningful results. It used random 2000 - 40000 configurations that are equally probable. Then the correction was performed by multiplying M_i the appropriate statistical weight (Boltzmann distribution) [10]. The magnetization of 1 or about 1 is thus practically excluded. It is conceivable that it is closer to reality than the original Ising model [11]. It is unlikely that, in the absence of an external field, the dipoles in a realistic structure have an ideally parallel arrangement.

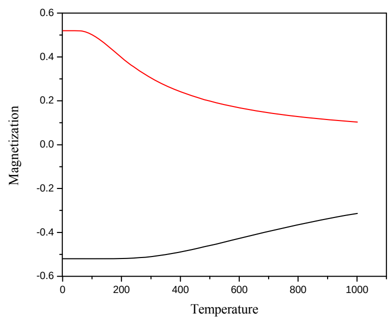
3. RESULTS

In Table 1. are presented results of computational experiments.

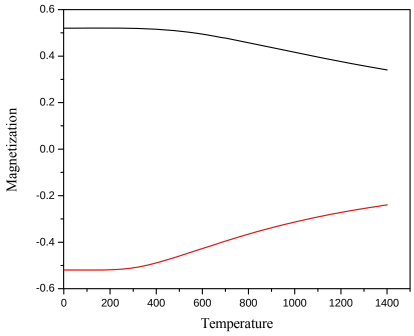
a) $N = 5$, $\varepsilon = 85000$, $\alpha = 0.0$ black line, $\alpha = 0.07$ red line, $i = 20000$



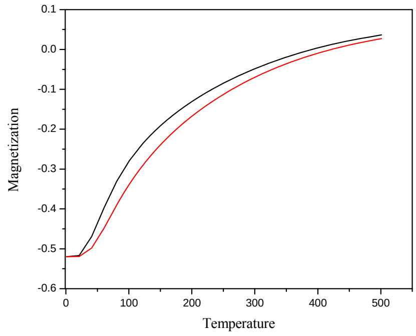
b) $N = 5$, $\varepsilon = 85000$, $\alpha = 0.9$ black line, $\alpha = 0.945$ red line, $i = 20000$



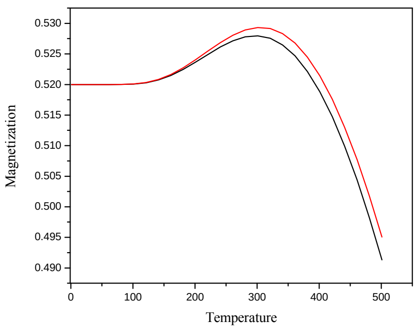
c) N = 5, ε = 85000, α = 0.94 black line, α = 0.95 red line, i = 20000



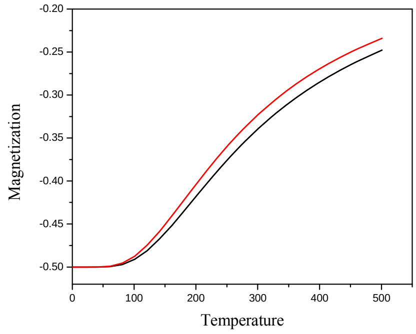
d) N = 5, ε = 850, α = 0.98 black line, α = 0.99 red line, i = 20000



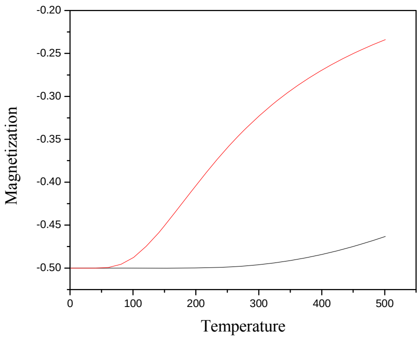
e) $N = 5$, $\varepsilon = 850$, $\alpha = 0.51$ black line, $\alpha = 0.5$ red line, $i = 20000$



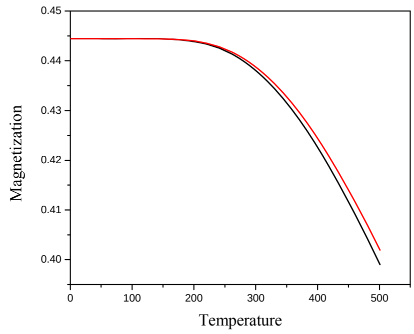
f) $N = 6$, $\varepsilon = 8500$, $\alpha = 0.35$ black line, $\alpha = 0.36$ red line, $i = 40000$



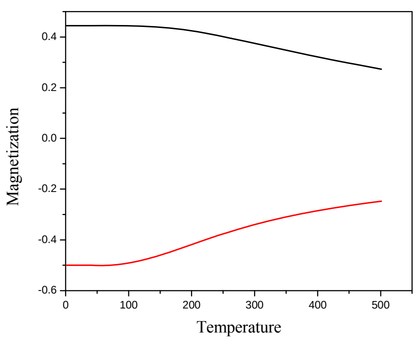
g) $N = 6$, $\varepsilon = 850$, $\alpha = 0.01$ black line, $\alpha = 0.09$ red line, $i = 40000$



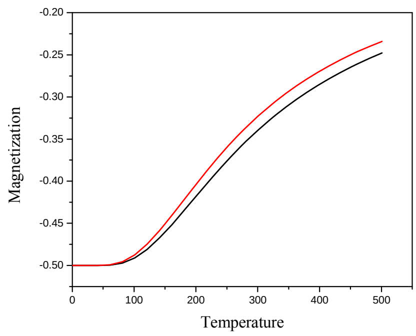
h) $N = 6$, $\varepsilon = 850$, $\alpha = 0.91$ black line, $\alpha = 0.92$ red line, $i = 40000$



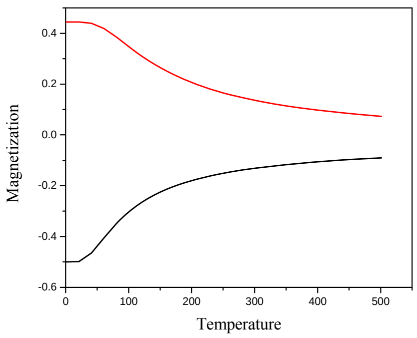
e) $N = 6$, $\varepsilon = 850$, $\alpha = 0.70$ black line, $\alpha = 0.35$ red line, $i = 40000$



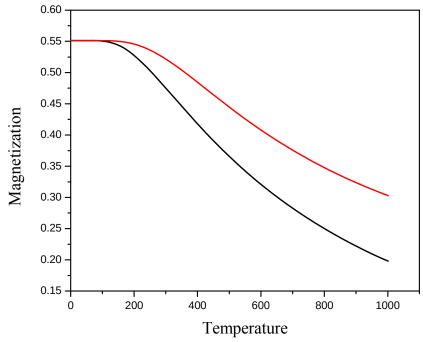
j) $N = 6$, $\varepsilon = 8500$, $\alpha = 0.35$ black line, $\alpha = 0.36$ red line, $i = 40000$



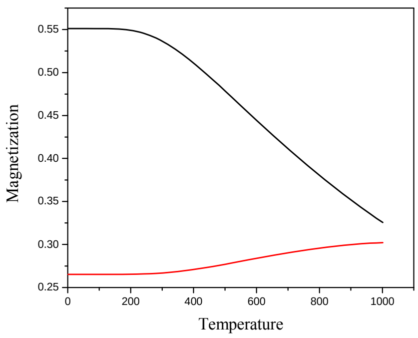
k) $N = 6$, $\varepsilon = 8500$, $\alpha = 0.48$ black line, $\alpha = 0.49$ red line, $i = 40000$



l) $N = 7$, $\varepsilon = 5000$, $\alpha = 0.37$ black line, $\alpha = 0.52$ red line, $i = 30000$



m) $N = 7$, $\varepsilon = 5000$, $\alpha = 0.37$ black line, $\alpha = 0.67$ red line, $i = 30000$



n) $N = 7$, $\varepsilon = 5000$, $\alpha = 0.3$ black line, $\alpha = 0.31$ red line, $i = 3000$

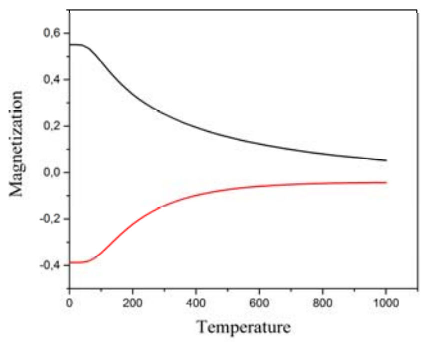


Table 1. Presentations of geometric reversals of magnetization

4. CONCLUSION

The Ising model is some kind paradigm among magnetic models [11]. One dimension Ising model is the simplest and presents a phase transition at temperatures different from zero. Ising models have found applications in areas away from solid – state physics, such as immunology [12] or stock market theory [13].

In this paper, presented are the results of computational experiments. In this paper, it was used simplified two – dimensional Ising model to simulate behavior of magnetization in relations to small change of energy interactions. All the simulations run on small Ising systems. It was noticed that small change of energy interactions (variations of parameter α) has significant effect on change of direction of magnetization vector. That can be linked to reversals of the Earth magnetic field. In Table 1, in pictures b), c), e), g), k) and m), it is visible reversal of magnetization for small variation of parameter α. It is very important to report that it can be feasible for a precise number of configurations. Also, in other pictures presented here, (a), d), e), f), h) and l)) we can see that reversals do not happened if it is not set exact number of configurations. One should be careful, when interpreting the model properties, because numerical value of magnetization is not correct. This model is very simplified model, and it should be upgraded in the further work.

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МОГУЋИ УЗРОЦИ ПРОМЈЕНЕ СМЈЕРА МАГНЕТНОГ ПОЉА ЗЕМЉЕ

Сажетак: Изучавање магнетних особина материјала одавно привлачи интересовање научника. Познавање магнетних особина материјала омогућава њихову што бољу примјену у индустрији и техници, као и што боље познавање неких још неразјашњених појава у природи везаних за магнетно поље Земље. Познато је неколико модела који описују дати феномен, као што су домино модел, дводимензионални Изингов модел и модел инверзије магнетног поља Земље. У рачунарским експериментима чији су резултати приказани у овом раду, кориштен је упрошћен дводимензиони Изингов модел, једна од верзија модела везаних спинова. Рачунарски експерименти (симулације) су рађене у математичком софтверу Maple. Примијећено је обртање смјера магнетизације при малој промјени нехомогености енергије интеракције. Разматрање овог проблема могло би бити од значаја за истраживање феромагнетних материјала.

Кључне ријечи: Болцманова расподјела, Изингов модел, магнетизација, нехомогеност енергије интеракције, геомагнетно поље.