A New Look On the Nature of the Earth's Magnetic Field

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Abstract. There was examined the model of the Earth's dipole magnetic field based on the existing geothermocurrents in the Earth's core, that occurred because of the geothermal gradient and the related Seebeck effect. The calculations showed, that the energy of geothermocurrents is enough to keep Earth's Magnetic Field (EMF) at the present level, that is about (3 – 5)·10⁻⁵ T. EMF model is quite innovative in comparison to the known electrical models, because it contains two branches of the planetary thermoelectrical element: “inner core – outer core – lower mantel”. These branches are connected through the more warmed and melted outer core. If the thermocurrents are simultaneously directed to the Earth's surface, a thaw period comes. If they are directed oppositely an ice age comes. As the directions of thermocurrents in the inner core change, EMF poles get inverted. At the moment of their inversion dipole magnetic field decreases up to its transitional disappearance. At the same time the pole caused by the lower mantel stays as 4.6·10⁻⁶ T. Thermoelectrical EMF model is universal. It enables us to calculate magnetic fields of any planet within the Solar System.

1. Introduction

There were a lot of attempts to explain the Earth's magnetic field by thermo electromotive forces inside the core, caused by turbulent convective moves of the core's liquid Elsasser [1] or by difference of temperatures between the cold mantel and the hot core, causing Hall effect [2]. However, these explanations were not developed due to lack of knowledge of physical conditions around the border between the core and the mantel. There was also a version including a charged interface between the mantel and the core [3], which has been developed lately in attempt to prove existence of double electrical layer (DEL) on both the borders of the Earth's crust F, transitional zone from the outer core to the inner one [4]. Even if we can agree with justification of the DEL model, despite the proof's speculativeness and the needed temperature conditions 30 000 K for the core, the reckoning values of the total magnetic field for oppositely charged surfaces of the Earth's crust F are still negligible (10⁻¹⁰ T). So, whatever the model is, it is inevitable to find an elusive but at the same time stable (outer or inner) source of generation, bringing this rough field to the real value of the Earth's magnetic field.

2. About thermoelectrical phenomena inside the inner layers of the earth

It is proved in the work [5] that geothermal gradient plays main role in forming additional thermoelectrical potential imposed on natural electronic conductors (metal ores, graphitic rocks). There is always a difference of temperatures between the end points of the latter, that, according to the thermoelectric effect, causes thermoelectric potential [6]:

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\[
\Delta \varphi_T = \int_{T_i}^{T_0} \beta dT
\]

So, regarding geothermal gradients' model in planetary scale we can create a consistent dynamic model of the EMF. To solve the problem, we are going to consider the existing scientifically justified data [4, 7, 8].

3. Thermoelectrical model of the Earth's magnetic field
Firstly, the liquid shell of the Earth E (outer core) is the hottest part of the planet. Secondly, the inner core G is colder, as it is solid.
So we can conclude, that there exist geothermal gradients directed oppositely to the Earth's shell E, and we can propose a possible schematic model of the Earth's geothermoelectric field (fig. 1.a).
Let us consider a case when the flows of thermocurrents, directed to the centre of the Earth \( I_{low} \) from the shell E, gradually increase concentration of electrons in the inner core because of absence of discharge channels (outer borders) and, hence, absence of dissipation of charges. That leads to the increase of the current density and then to the increase of Joulean heating. Consequently, the temperature \( (T_i) \) of the inner core reaches the temperature of the outer core \( (T_0) \), i.e. \( T_i = T_0 \). From that moment electrical currents \( I_{low} \) vanish, and the type of charge in the core centre can momentary change to the opposite for several times because of more high-frequency alternant pulsation of temperature \( T_0 \) in the E shell.

![Figure 1](image-url)

**Figure 1.** Plan of the trajectories of "hot" electrons (thermocurrents) within the Earth under impact of the geotemperature difference: a - for the model of the Earth with its inner core's temperature decreased; b - for the model of the Earth with its inner core's temperature increased. c – the model that explains the displacement of the magnetic dipole's center to the Earth's center.

As the process is inertial, the inner core temperature gets higher for some time till it reaches a stable state \( T_i > T_0 \), that immediately causes appearance of thermocurrents \( I_{low} \) of the opposite direction and...
change of polarized charges' types (going to model b (fig. 1,b)). Realness of such condition corresponds to the known researches of the cooling of the inner core for about 50 K/10^9 years, e.g. 7.2 \(^{0}\)C/10^9 years [9]. From that moment the Earth goes to its warmer mode. Electrons leave the inner core and following reduce of electrons concentration it gets colder little by little. As soon as the moment of the steady state \(T_{i} < T_{0}\) comes, a new and opposite process of thermocurrents inversion begins. The Earth goes to its colder mode. So, the cyclic change of thermocurrents' directions in the inner core goes at the same time as periodical change of the geomagnetic field's types does.

Let us calculate electrical and magnetic features of the Earth that are based on the cyclic circulation of thermocurrents in the core \(I_{low}\) and the mantel \(I_{top}\). To calculate magnetic induction \(B\) (next: \(B_{low}\) for the core, and \(B_{top}\) for the lower mantel), the main magnetic field's characteristic, the analogue of the Biot-Savart formula was found, which works for a non-standard spherical current source, that moves these currents from the centre of the sphere (to the centre of the sphere) towards radial directions:

\[
B_{low}^{TT} = \frac{3\mu_{0}\mu_{Fe}I_{low}R_{Z}}{4\pi R_{Z}^{2}}\sin\alpha ,
\]

where \(\mu_{0}\mu_{Fe}\), \(\mu_{Fe} = 1\) (Fe of the core is higher than the Curie point), 1.26 \(\cdot\) 10^-6 H/m; \(R_{Z} = R_{G} + \Delta R_{Fe} + \Delta R_{E}\) is total radius of the core, it is 3.65 \(\cdot\) 10^6 m; \(R_{Z}\) is Earth's radius, it is 6.37 \(\cdot\) 10^6 m. Dimension \(I_{low}\) is found from:

\[
I_{low} = jS_{G} = 4\pi R_{G}^{2}j, \quad [A]
\]

Where \(S_{G}\) is spherical surface of the inner core with radius =1.4 \(\cdot\) 10^6, m. At the same time, using the Quantum theory of the electrical conductivity of metals and semiconductors [10, 11], we can find the density of the hot core's thermocurrents:

\[
j = e^{2}nE_{T}l/p_{F}, \quad [A/m^{2}]
\]

where \(e\) is the charge of electron, 1.6 \(\cdot\) 10^-19, C; \(n\) is concentration of electrons in a unit of metal (Fe) volume, m^3, which can be calculated with the formula, reckoning in the pressure inside the core \(p=3.59 \cdot 10^{14}\) Pa:

\[
n = \left(\frac{3m_{e}}{\hbar^{2}} (3\pi^{2}n^{3})^{2/3}\right)^{3/5} p^{3/5}
\]

where \(m_{e}\) is the mass of the electron, 9.1 \(\cdot\) 10^-31, kg; \(\hbar\) is Planck's constant, 1.05 \(\cdot\) 10^-34 J\(\cdot\)s; \(p_{F}\) is Fermi momentum, [m\(\cdot\)kg/s], and can be calculated from:

\[
p_{F} = \hbar \left(3\pi^{2}n\right)^{1/3}
\]

\(l\) is the medium distance of electrons’ mileage between concussions with the crystal cell, it can be found from the formula:

\[
l = \frac{\sigma \hbar (3\pi^{2})^{1/3}}{e^{2}n^{2/3}}, \quad [m];
\]

where \(\sigma\) is the electroconductivity of the planet’s core, [S/m]. To calculate \(l\) we should take \(\sigma\) as 10^5 S/m as a minimum value from the range of the Earth’s core electroconductivity 0.1 \(\div\) 1.0 million S/m, published earlier [4]. Using the corresponding parameters
and constants in the formulas (5, 6, 7), we get \( n = 3.25 \cdot 10^{29} \text{ m}^{-3} \), \( p_F = 2.24 \cdot 10^{-24} \text{ m} \cdot \text{kg/s} \) and \( l = 0.135 \text{ nm} \).

Thermofield tension \( E_T \) of the Earth's core with the difference of temperatures \( \Delta T = 10^6 \text{C} \) and radius \( R_\Sigma \) can be found with use of the formula (1):

\[
E_T = \beta dT / R_\Sigma , \quad \text{where} \ \beta = 0.0001 \text{ V/deg}. \tag{8}
\]

Its value is determined as \( 2.74 \cdot 10^{-10} \text{ V/m} \).

After having substituted the calculated parameters \( n, p_F, l \) and \( E_T \) to the formulas (5, 4) beforehand and having defined the main characteristics of the core \( I_{low} \) and \( j \) we can finally find the value of magnetic induction \( B_{T_I} \text{low} \) on the Earth's surface, that is \( 3.49 \cdot 10^{-6} \text{ T} \). The latter is almost like the value of magnetic induction \( B_0 \), measured on the equator, that is \( 3.4 \cdot 10^{-5} \text{ T} \). Hence, thermoelectrical currents cause not just an insignificantly small elementary field, but the main dipole magnetic field of the Earth. The calculations also show that the inner core must be metal, because the formula (8) contains temperature coefficient \( \beta \), which is 0.0001 V/0°C for pure metals and affects all the main parameters of the core: \( E_T, j, I_{low} \).

Furthermore, the thermoelectrical model under consideration allows to explain the tilt of magnet axis upon the Earth's one with Coriolis and centrifugal inertial forces' affection on the flows of electrons. It also explains the distance between the magnet axis' center and the Earth's axis' centre which is nearly \( \Delta X = 0.07 \cdot R_\Sigma \), that is shown on the Figure 1 a, c.

At the same time, the currents, that move unidirectional from the lower mantel to the shells C, B, and A, cause volumetric positive electric field inside these shells (fig. 1 b). The latter is maintained at the level higher than its dissipation because of the constant difference of temperatures \( \Delta T \) between the shells E an B within 4000 °C. According to the calculations from the formula (2), considering constants and parameters peculiar to the lower mantel its magnetic field \( B_{T_I} \text{low} \) is \( \sim 4.6 \cdot 10^{-6} \text{ T} \), that is way less \( B_{T_I} \text{low} \). Therefore, lower mantel thermocurrents' field is not capable of generating the required intensity of geomagnetic field because of the following reasons: a) the rocks are semiconductors, b) specific conductivity of the rocks is about \( 0.1 \div 10 \text{ Sm/m} \) [4], c) electrons concentration in the semiconductors is not more than \( 10^{20} \text{ m}^{-3} \) on the average.

4. Model of Earth's magnetic field-tested on Mars

It is important, that the suggested model allows to explain the absence or insufficiency of magnetic fields of neighbour planets of the Solar System more correctly. Particularly, any cooled planet with a cold metal core is going to have only a relict magnetic field. For example, let us make the calculations of Mars' magnetic field. First, Mars has physical and temperature features similar to the solid body of the Earth. However, Mars' model doesn't have any melted outer core. Let us consider the radius of the Mars' hot core to be 1480 km, and the difference of the temperatures between Mars' centre and the outer border of its core to be about 10°C. Then Mars' magnetic induction \( B_M \) on its surface is going to be \( 3.57 \cdot 10^{-6} \text{ T} \) that is almost 10 times less than the Earth's one. Going on calculating, we should take into account that Mars is a cooled planet, its metal core is cool, that's why the difference of temperatures \( \Delta T \) is obviously less than 1°C (let us take it as it is 0.17°C). In that case the magnetic field on the Mars' surface must be \( B_M = 6.07 \cdot 10^{-8} \text{ T} \) or about 61 \( \gamma \) (1 T = 10^6 \( \gamma \)), that coincides to the data of the measuring of the magnetometers of the SPs Mars 2 and Mars 3 [12]. Calculations showed the Mars' magnetic field is 575 times weaker than the Earth's one. This leads us to conclusion that despite a great similarity between Mars' structure and compound and the Earth's ones and similar rotation speeds of these planets, Mars and suchlike planets with cold metal cores are not able to generate intensive magnetic fields because of the absence of thermoelectrical currents and the field \( E_T \).

5. Conclusions

In the issue, the considered model of the Earth's magnetic field gives physically and logically justified answers to principled questions, related to the way geomagnetic field acts in space and time. The
model is based not on the hypothetical convectional processes in the outer core with a lot of restrictions, but on the real geothermal gradient and physical law, related to the thermoelectric effect. The latter are always available for research and modelling of the Earth's processes.

Thermoelectrical model of the Earth’s magnetic field is based on the difference of geotemperatures, a real and constantly functioning source of thermoelectrical energy inside the metal core. In the issue, there are always cyclically circulating thermoelectrical currents, caused by the thermoelectric effect, inside the metal core. The thermocurrents are cyclic because the difference of the temperatures on the ends of the spherical conductor “inner solid core – outer melted core” changes its sign and is accompanied by inversion of the geomagnetic field poles. From the physical point of view, thermoelectrical processes take place inside our planet according to the known physical laws, that do not demand any theoretical restrictions or complements. For the first time the EMF model, in comparison to many other known models, including the magnetic dynamo of the Earth, makes it possible to give physically and logically valid answers to a lot of questions about how a geomagnetic field acts in space and time.

This EMF model is universal, it explains correctly the reason of magnetic poles inversion, cyclic change of warm and cool periods, specifies the values of electroconductivity and the conduct of the Earth’s core, gives us an opportunity to use a new physically valid approach for calculating electrical and possibly lithological features of the Solar System planets with the data of their magnetic fields and some other, taken by satellites. The model is simple and can be easily used for modelling the Earth’s processes in a laboratory.

Studying the Earth’s thermoelectrical field is going to give the scientists all over the world an opportunity to create an effective way to overcome the oncoming global catastrophe caused by the increasing planetary warming.

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