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Abstract: The exact explanation of the origin of magnetic field of the Earth and other planets does not yet exist. There are several hypotheses, theories and experiments, trying to find a solution to this problem, but the final, rigorous proof of these hypotheses does not exist. This article discusses the hypothesis that the main reason for the emergence and maintenance of the magnetic field is the ionosphere, containing the charges, which are recharged by the solar wind. This approach allowed us to explain a number of observed phenomena, including the inversion of the magnetic field of the Earth and planets. On the basis of these estimates the calculations of magnetic fields of other planets were carried out and demonstrated good agreement with measurements. There was a number of assessments carried out, which showed the correctness of this approach.

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Cover Letter

Dear Mr.Buffett,

Please see attached my article “Origin of Planetary Magnetic Fields”. I am a Dr. of Science in Geophysics having worked for 7 years in the Russian Space Research Institute No. 1, where I worked on the theory of plasma rocket engines. Currently I am a Chief Scientist at Petroenergy Global LLC working on various problems in oil and gas industry.

Please see my resume on my website: www.tseytlin-consulting.com

Thank you for your time and consideration.

Thanks,

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As of yet there is no accurate theory explaining creation and maintenance of planetary magnetic fields. There are several hypotheses, theories and experiments trying to find a solution to this problem, but there is no final, rigorous proof of these hypotheses.

This article discusses the hypothesis that the main reason for the emergence and maintenance of this field is because of the charges in planet's atmosphere and ionosphere and their recharging by the solar wind.

Origin of Planetary Magnetic Fields

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As of yet there is no accurate theory explaining creation and maintenance of planetary magnetic fields. There are several hypotheses, theories and experiments trying to find a solution to this problem, but there is no final, rigorous proof of these hypotheses.

This article discusses the hypothesis that the main reason for the emergence and maintenance of this field is because of the charges in planet's atmosphere and ionosphere and their recharging by the solar wind.

Following are a number of estimates, which show the validity of this approach.

1. Let's concentrate on Earth first. The solution for the magnetic field of a rotating surface of a charged sphere is discussed in ([1], [2]). The magnetic moment of a rotating sphere is

$$\vec{m} = \frac{Qa^2\vec{\omega}}{3c}$$

where:

$R = 6{,}340{,}000$ m - radius of Earth,

$\omega = 7.3 \cdot 10^{-5}$ 1/sec - speed of rotation of the Earth,

$c = 300{,}000{,}000$ m/sec - speed of light.

It is known [1] that the Earth's magnetic moment is $M = 8 \cdot 10^{25}$ units CGS. Then, knowing the magnitude of the moment of Earth's magnetic field M, we define the quantity required for this electrical charge.

$$Q = 0.245 \cdot 1023 \text{ CGS} = 8.1 \times 10^{13} \text{ C}.$$

It should be noted that a more accurate estimate of the charge can be made based on the assumption that the charge is in a spherical layer of Earth's surface and has a thickness equal to a few hundred kilometers, giving approximately the same value $7.5 \cdot 10^{13}$ C.

2. On the other hand it is known (for example [3]), that the Earth has a charge on the order of:

$$Q_{Earth} = 5.7 \cdot 10^{5} \text{ C}.$$

It follows that it is not enough to create Earth's magnetic field.

Suppose that there is an additional charge of a different nature, creating it.

Let’s determine its nature.

3. We need to pay attention to the following circumstances:

3.1 Earth has a strong magnetic field. Venus, Mars and most other planets have magnetic fields hundreds of times less.

3.2 Only Earth has air and water! This allows us to make the hypothesis that the Earth's magnetic field is due to the charge of the clouds. Its value is enormous.

It is known that a lightning discharge power reaches 100 Megawatt and every second around the Earth there happen 46 lightning discharges.

Let’s estimate the charge of the clouds, assuming that the system consisting of clouds and the surface of the ground forms a spherical

capacitor. It is known that: $Q_c = C \cdot U$, where the capacity of a spherical capacitor is:

$$C = \frac{4\pi E_{ps} R_1 R_2}{R_1 - R_2}$$

where:

R_1, R_2 – outside and inside radius of the sphere: R_1 = 6350 km, R_2= 6340 km,

$E_{ps} = 8.85 \cdot 10^{-12}$,

It should be noted that, given that water has relative permittivity of 80, the capacity of the cloud layer may be higher by one or more orders.

That yields us approximately C = (0.45-4.5) Farads.

Let's estimate the potential difference U between the clouds and the Earth's surface. We take E = (10-30) Kilovolt to 1 cm as voltage of air breakdown. Then:

$$U = E \cdot H = 3 \cdot 10^6 \cdot H \text{ Volt},$$

where

$H = (1\text{-}10) \cdot 10^3$ m - height of the clouds.

The result is an upper bound of the charge of the clouds on Earth:

$$Q_{1\,max} = C \cdot E \cdot H = 4.5 \cdot 3 \cdot 10^6 \cdot 10^4 = 1.35 \cdot 10^{11}\ C.$$

It should be noted, that deposits of iron and nickel in the upper part of the crust, can also increase the magnetic field of the Earth.

As a result, the charge of the clouds can create a sufficiently strong magnetic field commensurate with the Earth's magnetic field.

4. The following additional estimate of Earth's magnetic field gives approximately the same result.

The work [4] contains an assessment of the charge densities of thunderclouds.

At any given time in the world there are simultaneously about a thousand storms, the average frequency of lightning discharges is estimated as 46 per second. The storms are unevenly distributed on the planet's surface.

As a result, of calculations and experiments given in the work, the density of the charge is in the range $q = (9\text{-}280) \cdot 10^{-9}\ C/m^3$. Then, taking the amount of cloud cover in the form $V = 4\pi \cdot R^2 \cdot H$, where H = 1000 m - thickness, we get:

$$V = 50 \cdot 10^{17}\ m^3$$

Then we obtain an estimate of the charge of storm clouds on Earth, which varies in the range of

$$Q_1 = V \cdot q = (4.5\text{-}140) \cdot 10^{10}\ C.$$

Assuming that the storm clouds take up one-tenth of the sky, and they have the lowest charge density, we get a lower estimate of the charge equal to

$$Q_{1\ min} = 4.5 \cdot 10^{9}\ C.$$

The maximum estimate will then be equal to

$$Q_{1\ max} = 1.4 \cdot 10^{11}\ C,$$

which practically coincides with the estimate obtained in the previous section.

This evaluation indicates that the charges inside Earth's atmosphere can be a major contributor to Earth's magnetic field. However, they are not enough. Additional contributors could be the presence of iron in the Earth's crust and charges in the Earth's ionosphere.

5. One of the missing links in determining the Earth's magnetic field may be the effect of the upper layer of the earth's crust to a depth of 15 kilometers, where the iron and nickel deposits are located, which have a temperature below the Curie point (equal to 768 degrees Celsius). The deposits of iron and nickel make up 5% of the total weight of the Earth’s crust and 30% of its volume. They may influence the magnitude of the magnetic field of the Earth, increasing it by a few times. Note that the total amount of iron in the world has not changed over time. Even though some was removed from the Earth’s crust, it is still on its surface.

6. This theory of occurrence of Earth's magnetic field can also explain the presence and magnitude of the magnetic field of other planets.

6.1. This is especially true of Venus. Venus is the most Earth-like planet that does not have a strong magnetic field, but the internal structure is thought to be very similar. Venus has an ionosphere and an atmosphere, consisting mainly of CO_2 gas, which have a certain electrical capacity,

and which are constantly recharged by the solar wind like on Earth. It should also be noted that the length of day on Venus is more than 243 times greater than on Earth. Thus the velocity of charges in the ionosphere of Venus is hundreds of times slower than in the Earth's ionosphere, which explains why the magnetic field of Venus is less than the magnetic field of the Earth by 300 or even more times.

6.2. Consider Mercury. It is well known that its magnetic field is more than a hundred times smaller than the Earth’s one. On the other hand the length of its day is over 58 times longer than on Earth, and its radius is 2440 km. It follows that the velocity of negative charges in the ionosphere of Mercury is 152 times slower than the Earth's ionosphere. This may explain the decrease in its magnetic field, as compared to Earth.

The site [7] indicates that the measurement of the magnetic field of Mercury is 0.006 of the magnetic field of the Earth. That means it’s 150 times smaller, which coincides with our assessment!

6.3. Let's consider now the magnetic field of Jupiter. It is known that Jupiter has a magnetic field approximately 20 times greater than the Earth.

It is known that the radius of Jupiter is 11 times greater than the radius of Earth, and the rotational speed is 2.4 times greater. So the velocity of the charges in the ionosphere of Jupiter in 26.4 times greater than the Earth's ionosphere. Measurements have shown that the magnetic field of Jupiter is 20-50 times greater than the magnetic field of the Earth. In this case, the magnetic field of Jupiter calculated via the present theory also gives good agreement with the measurement!

6.4. Mars seems not to be subject to existing theories. The magnetic field of Mars is extremely small - more than 500 times weaker than the magnetic field of Earth. The size of Mars is only half smaller and its rotational speed is similar to Earth. Therefore all the conditions for the operation of the mechanism similar to hydrodynamic dynamo should similarly create a magnetic field. However, the difference in the observed magnetic field is due to the actual current lack of Mars's atmosphere and ionosphere. The pressure of the atmosphere at the surface of Mars is 160 times smaller than the Earth. This proves that the source of the magnetic field depends on the presence of the ionosphere, because the rest of the parameters of the planets are somewhat similar. Analysis of tectonic rocks shows that at some time in

the past, the magnetic field of Mars was quite noticeable and demonstrated reversal of the magnetic field. We know that the loss of Martian atmosphere is relatively recent, and the process still continues right now. The lack of atmosphere and magnetic field are the main reason for the absence of life on Mars, but does not rule out its existence in the past. There exist several hypotheses of the cause of the loss of Martian atmosphere, but we will not dwell on them.

The fact is that in the absence of an atmosphere and ionosphere a planet's magnetic field cannot exist.

Thus we have another indication that magnetic fields of planets exist due to their atmosphere and ionosphere. If the hydrodynamic dynamo mechanism actually applied instead, it would have continued to work on Mars and produced a magnetic field similar to the Earth's magnetic field.

7. Let’s put the data on several planets in one table.

Planet	Diameter [km]	Rotation [hr]	Relative Magnetic Field	Relative Atm. Pressure

Mercury	4879	1411	0.006	0.001
Venus	12104	5851.2	0.003	93
Earth	12742	24	1	1
Mars	6779	24.6	0	0.06
Jupiter	139822	9.92	25	12

Table 1

From Table 1 we can make the following conclusions:

7.1. On planets with no atmosphere and no ionosphere, the magnetic field is either negligible or not present (Mercury, Mars).

7.2. From the comparison of Earth and Mars, if the hydrodynamic dynamo hypothesis were right, then they would have both had a magnetic field. But only Earth has one! **So the hydrodynamic dynamo hypothesis is incorrect.**

7.3. Radiuses and rotational speeds of the planets determine the velocity of the charges in the ionosphere. And hence the current.

It follows that on the planets that have an atmosphere and ionosphere, where the magnetic field is generated according to our hypothesis - from the solar wind, its strength should be proportional to the linear velocity of the ionosphere, so we could multiply the radius by the angular speed!

Indeed Venus, which has a radius slightly smaller than Earth, but with rotating 243 times slower, the strength of the magnetic field is nearly 300 times smaller. Jupiter, which has a radius of 11 times larger than the Earth and rotating with an angular velocity 2.4 times faster than the Earth, the magnetic field is ~25 times greater.

These estimates confirm the correctness of our hypothesis that the mechanism of creation of the Earth's magnetic field is by moving charges in the ionosphere, which are created by solar wind.

Hence, our hypothesis of the emergence and maintenance of the Earth's magnetic field is a better explanation then the hydrodynamic dynamo hypothesis of its origin.

8. Note that the present hypothesis about the cause of Earth's magnetic field makes it easy to explain not only the origin of the field, but also the geomagnetic field inversion that occurs every several hundred thousand years in a stochastic manner.

Analysis of the Earth's magnetic field, conducted with the help of satellites and modeling has shown that the solar wind currently bends around it, because it mainly contains electrons with negative charge (Fig. 1). In case of

a positive charge in the solar wind the form of Earth's magnetic field would have been different.

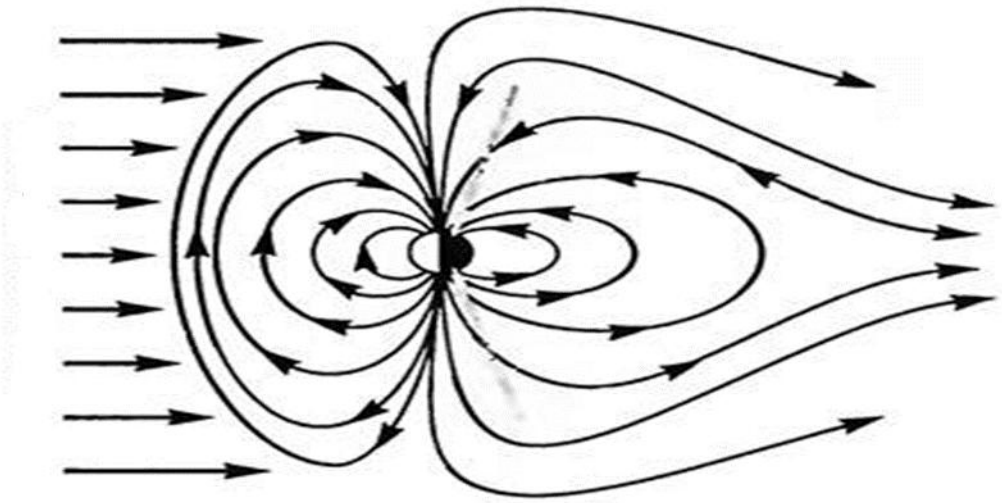
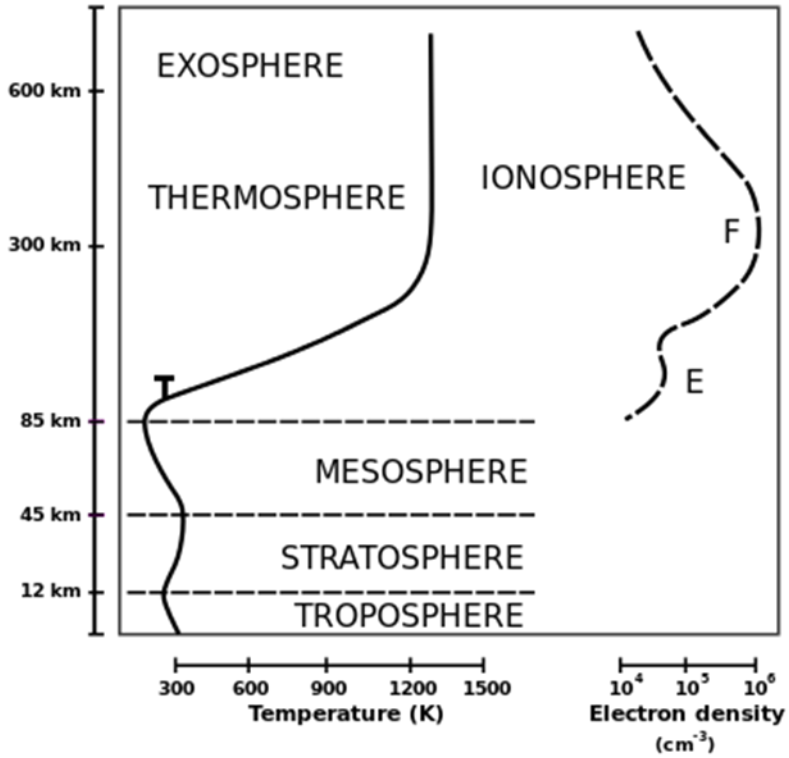


Fig.1 – Magnetic field of Earth

Solar wind is a stream of charged plasma, ejected from the surface of the Sun that overcomes the gravity and the magnetic attraction of the sun and propagates in all directions. Part of this wind reaches the Earth's ionosphere and charges it with a negative charge. The ionosphere contains the so-called E and F layers [6] (Fig. 2) created by the solar wind, located in the region of 90 to 500 km above the surface of the Earth and having electron density in the range of $N_e = (1.5\text{-}30) \cdot 10^5$ per cubic centimeter [3]. The average value of the electron density there is $N_e = 10^6$ 1/cm^3.



215

216 Fig. 2 – Distribution of electron density and temperature vs. height.

217 As the thickness of the E and F layers is up to H = 500 km, it is easy to

218 estimate their total charge. It is

219 $Q = Q_e \cdot R^2 \cdot 4\pi N_e \cdot H = 1.6 \cdot 10^{-19} \cdot 41 \cdot 10^{16} \cdot 12.6 \cdot 10^6 \cdot 5 \cdot 10^7 = 4.14 \cdot 10^{13}$ C

220 Where $Q_e = 1.6 \cdot 10^{-19}$ C is the charge of an electron.

221 **We have demonstrated that the charge of the E and F layers of the ionosphere,**

222 **and considering the additional effect of the iron contained in the upper layer of**

223 **the Earth's crust, would be sufficient to establish, or at least make a major**

224 **contribution to the formation of Earth's magnetic field.**

It should be noted that due to the constant ejection of negatively charged particles as part of the solar wind, the Sun gradually gains an excess positive charge. This leads us to the fact that periodically, every few hundred thousand years, the sun begins to emit positively charged gigantic coronal mass ejections (predominantly due to their content of positive ions and protons), dimensions reaching several thousand kilometers. Therefore the solar wind starts bearing a positive charge, and when it reaches Earth it recharges its electric and magnetic fields.

As a result through some period equal several thousand years, the Sun again becomes neutral in charge and starts letting out negatively charged wind again.

This results in the next inversion of the magnetic field of Earth. The recharge of the magnetic field of Earth can occur as well as a result of collision of Earth with big comets which can be charged either negatively or positively, depending on the sign of the charge of the star which the comet encountered before it.

So the process of inversion of the magnetic field of Earth can be explained easily on the basis of the offered hypothesis.

9. Now we will briefly discuss other approaches to explanation of emergence of the Magnetic Field of Earth. First of them is the

explanation of emergence of the magnetic field of Earth via the mechanism of thermal convention in its liquid magma. Such hypothesis is based on the analogy of the mechanism of emergence and maintenance of a magnetic field of the Sun.

However a simple analysis shows that in the conditions of Earth this mechanism can't work because of a difference of scales and magnitudes of density and viscosity of the fluids and gradients of temperature existing on the Sun and Earth. It is known that a large gradient of temperature and presence of low viscosity fluid is necessary for effective thermal convection. But gradient of temperature of terrestrial magma from the top part adjoining the crust (700 ^{o}C), and the deeper part, adjoining the kernel (6000 ^{o}C) over the distance about 3000 km, gives the top assessment of average gradient of -2 ^{o}C per kilometer.

It is less than in crust of Earth and considering that viscosity of magma, even at a temperature of 4000 ^{o}C is very high – it is possible to draw a conclusion that under these conditions in Earth there can NOT be considerable thermal convection!

It should be noted also that maintenance of a magnetic field of Earth requires a lot of energy. As any electromagnetic generator has to use a rotating rotor, the role of which plays the Earth. Thus there are forces and inductive currents braking it. It needs additional energy to maintain constancy of speed of its rotation, or it has to slow down, losing rotational speed. But over millions of years Earth's rotational speed almost didn't change.

This proves that on Earth there are insufficient conditions for operation of the mechanism of a hydro magnetic dynamo.

For comparison, on Sun temperature changes over depth from 6000 to 15,000,000 ^{o} C, and the fluid is represented by plasma (the ionized gas) density of which is one hundred times less than magma's, and viscosity of magma is one thousand times lower than viscosity of plasma. Under these conditions there can in fact exist strong magnetic fields thanks to the mechanism of a hydrodynamic dynamo.

10. Consider the following as further proof that magnetic field of Earth is due to the sources outside of its volume. The Earth's crust up to about 15 kilometers deep has the condition that temperature is less than the Curie's point, and this is where the fields of iron and nickel lie, making

about of 5% the crust's volume. When magnetic field of Earth is measured along its surface, it is greater in the regions where iron and nickel are present. But if the source of magnetic field is internal, the opposite effect should have been true, as metal would shield the field. Therefore the hypothesis about the sources of magnetic field of Earth being of external nature is true. And consequently, the version and the carried-out estimates about location of these sources in the atmosphere and an ionosphere of Earth are correct.

11. We will note that by means of the offered hypothesis it is easy to explain discrepancy between the geometric axis of Earth and the axis of the magnetic field of Earth (shift of magnetic poles).

This phenomenon arises because of an inclination of a geometrical axis of Earth to Earth orbit plane of 23.4 degrees. In this connection the solar wind falls on Earth surface at an angle.

12. Thus only the charges brought from the outside (solar wind or comets) and the charges resulting from formation of drops of a rain in clouds can constantly recharge the atmosphere and an ionosphere, allowing to create and support the magnetic field of Earth.

And the magnetic field of the atmosphere of Earth can serve as the initial starter of creation of the Magnetic field of Earth, originally braking and guiding electrons of the Solar wind at a tangent to Earth surface.

The carried-out estimates showed that the total charge of Earth, clouds and the ionosphere can provide emergence and existence of the magnetic field of Earth. And the charges arising in atmospheric clouds constantly are supported by the water circulation in the nature, and the charge of ionosphere is constantly recharged by the streams of charged particles coming from the Sun.

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