HYPOTHESIS OF PIEZOELECTRICITY OF INNER CORE AS THE ORIGIN OF GEOMAGNETISM

Y. Hayakawa

Dept of Clinical Medicine, Toin University of Yokohama, Kuroganecho, Aoba-ku, Yokohama 225-8502, Japan
Email: hayakawa@cc.toin.ac.jp

ABSTRACT

A novel hypothesis is proposed that assumes piezoelectricity of the inner core as the origin of geomagnetism. By high pressure, an electric charge is created on the surface and at the center of the earth. Inner core rotation yields a magnetic field. From the intensity and direction of geomagnetism at the present time, the surface charge density of the inner core is assumed to be $-2x10^{-5}C/m^{2}$. *The rotation axis of the inner core is inclined by 10.4 degrees from that of the mantle. The inner core rotates with the mantle rotation. The reason for this is thought to be the eddy currents induced in the outer core of electrically conductive fluid that rotates with the mantle.*

Keywords: Origin of geomagnetism, Piezoelectricity, Inner core, Novel hypothesis, Enthalpy, Gibbs free energy

1 INTRODUCTION

The origin of geomagnetism has not yet been sufficiently clarified. Although the dynamo process is the most dominant hypothesis, it is not valid in every respect and in every detail. Especially, the Ekman number between computer simulations and the actual outer core differs by at least three orders of magnitude (Whaler, 2007). The main non-dynamo theories are shown in Table 1 (Stevenson, 2007).

Table 1. Non-dynamo Theories (Stevenson, 2007).

1	Primordial Currents and Field
2	Permanent Magnetism
3	Off-diagonal Condensed Matter Physics Effect
4	Magnetic Monopoles
5	New Physical Theories Associated with Rotation
6	Rotating Electric Fields and Charges

The last theory "Rotating Electric Fields and Charges" is reconsidered in this work. Although this theory is stated to be physically impossible because it yields a high electric field of ~1011 Vm-1 that ionizes atoms (Stevenson, 2007), I found it is not the case. In this study, a hypothesis is proposed where ionization of iron atoms creates positive iron ions and negatively charged metal iron under the high pressure and high temperature in the inner core. These materials are partially separated and result in piezoelectricity of the inner core. The inner core is polarized by high pressure, resulting in an opposite electric charges at the surface and the center. The rotation of the globe (inner core) with surface charges yields circular electric currents and a magnetic dipole (Kraus & Fleish, 1999). The rotation axis of the inner core is inclined 10.4 degrees from the mantle's rotation axis. The charge density at the surface of the inner core is $-2x10^{-5}C/m^{2}$, assuming an inner core radius of 1220 km. The earth's rotation velocity (ω=7.3 x10^{-5} s^{-1}) determines the magnetic orientation and dipole of 8×10^{22} Am^{2} (Lowes, 2007).

2 CONSIDERATIONS

The following considerations are examined in this study: the origin of piezoelectricity from thermodynamics at high pressure and high temperature (Kaminuma, 1988); the difference of magnetic poles and poles of earth; the westward drift of geomagnetism (Holme, 2007), which may be related to the differential rotation of the inner core (Richards & Li, 2007); the geomagnetic relation with earthquake activity (Richards & Li, 2007); and geomagnetic reversal.

2.1 Thermodynamic consideration

In thermodynamics, the cause of piezoelectricity of the inner core was first considered to be enthalpy, thus neglecting the entropy and temperature from Gibbs free energy, where, at constant temperature and pressure, reactions are spontaneous in the direction of decreasing Gibbs energy (Atkins & Paula, 2002). Enthalpy H is given by

$$H = U + PV, \qquad (1)$$

where U is the internal energy, P is the pressure, and V is the volume, and Gibbs free energy G is given by

$$G = H - TS, \qquad (2)$$

where T is the temperature and S is the entropy.

The main elements constituting the inner core are iron, nickel, and sulfur. Because it is the largest constituent, only iron is taken into consideration in the following. Because the nature of iron is not known at high pressure (Kaminuma, 1988) and high temperature of ~6000 K (Kaminuma, 1988), as shown in Table 2, the nature of iron at room temperature and 100 kPa is used, as shown in Table 3 (Editorial Dept. Jikkyo Shuppan, 2005).

Table 2. Pressure in the Earth

Depth from the Surface (Distance from the center) [km]	**Common Name**	**Pressure** [GPa]
0 (6371)	Surface/Crust	
33 (6338)	Upper Mantle	13.3
400 (5971)	Transition Layer	
670 (5701)	Lower Mantle	23.8
2891 (3480)	Outer Core	136
5150 (1221)	Inner Core	329
6371 (0)	Center of the Earth	364

Table 3. Nature of iron at room temperature and 100 kPa (Editorial Dept. Jikkyo Shuppan, 2005)

Iron	**Atomic or ionic radius [pm]**	**Type of Energy**	**Energy [eV]**
Fe26	126		0
Fe^{+}	?	ionization	7.88
Fe^{2+}	83.5	ionization	16.21
Fe^{3+}	73.8	ionization	30.70
Fe^{-}	?	electron affinity	0.16
Fe electrons	[Ar] + 3d electrons :6 +4s electrons:2		

First, the enthalpy change from iron metals to positive iron ions and negatively charged iron metal was calculated. We used the atomic radii of 126 pm for iron metal and 83.5 pm for Fe^{2+} iron ions, which are the values for iron at the surface of the earth. Although, as was already mentioned, the inner core is under high pressure and high temperature, we have no reliable material data for iron at the inner core. Negatively charged iron metal was assumed not to increase in volume because the wave functions of electrons in the conduction bands are not much different from each other (Kittel, 1986). The change of enthalpy ΔH is given by

$$\Delta H = \Delta U + P\Delta V, \qquad (3)$$

where ΔU is the ionization energy minus electron affinity, that is, 16.21 eV – 0.16 eV per iron atom, which equals 16.05 eV (Figure 1). P is assumed to be 329 GPa, and ΔV per atom or ion is assumed to be $4*2^{1/2}4[(83.5\times10^{-12})^3-(126\times10^{-12})^3]$ (m^3), where the closest packing structure is assumed (Figure 2). The change of $P\Delta V$ per atom or ion is –16.49 eV. Therefore,

$$\Delta H = 16.05\ \text{eV} - 16.49\ \text{eV} < 0.$$

This means that ΔH is slightly decreased when iron is changed into a mixture of positive ions and negatively charged iron metal. Figure 1 shows the scheme for the calculation of the enthalpy difference at the inner core.

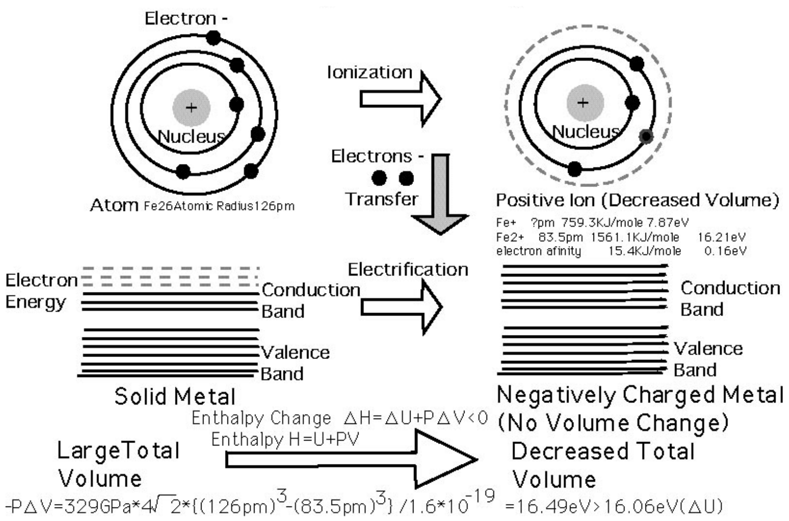

Figure 1. Calculation scheme of enthalpy decrease from iron to mixture of positive iron ions and negatively charged iron metal.

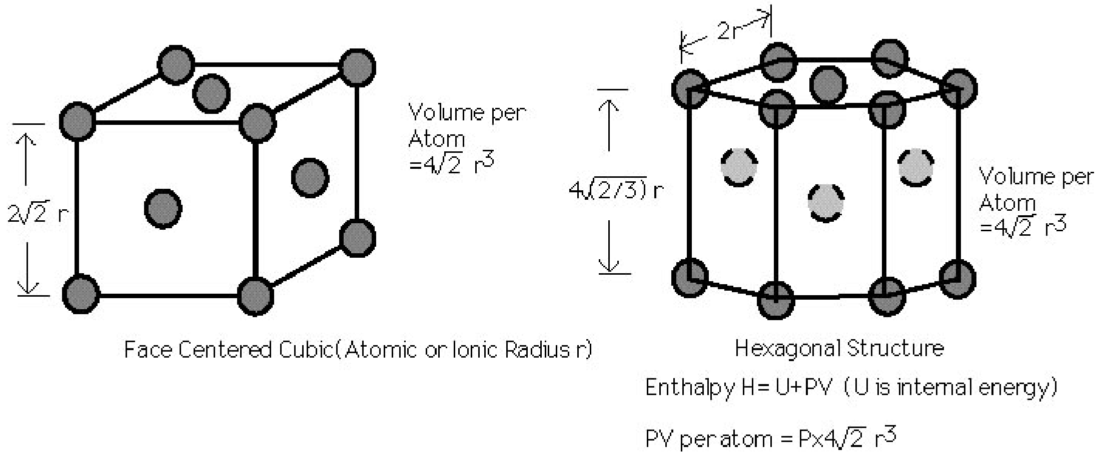

Figure 2. Assumed closest packing structure of iron in the inner core.

From the calculations, enthalpy (H=U+PV) was slightly smaller for the mixture of iron positive ions and negatively charged iron metal than for pure iron metal. The calculation, however, may not be valid for iron in the inner core because the nature of this iron is not well understood at the high pressure of 330 to 360 GPa. This calculation shows, however, that the enthalpy difference is small. Moreover, one has to consider the entropy at high temperatures (Gibbs free energy). The mixture of iron positive ions and negatively charged iron metal increases the complexity compared to neutral iron metal, and according to the Boltzmann formula, the entropy increases in the mixture (Atkins & Paula, 2002). Therefore, Gibbs free energy, G=U+PV-TS, where T is the temperature and S is the entropy, decreases in the mixture, resulting in a more stable mixture. Thus, the reason for piezoelectricity of inner core is partially explained.

2.2 Consideration of the difference of magnetic poles and the Earth's poles

As the magnetic axis is inclined 10.4 degrees from the mantle's rotation axis, the rotation axis of the inner core should rotate with the mantle rotation, 360 degrees in one day. This is due to eddy currents (Kraus & Fleish, 1999) that are induced in the liquid metal in the outer core and follow the mantle rotation. The eddy currents tend to oppose the change in the field inducing it (Kraus & Fleish, 1999). Therefore, the currents tend to stop the motion of the inner core rotation axis relative to the outer core rotation. It is reported (Laj et al., 1991; Valet & Herrero-Bervera, 2007) that when the geomagnetic reversal happened, the magnetic moment became weak and the magnetic poles approached the equator before and after reversion. This phenomenon may be due to the weakening of the magnetic field, resulting in decreased eddy currents.

2.3 Consideration of westward drift

If the inner core rotates at a slightly slower speed compared to the rotation of the mantle, the westward drift of the magnetic field is explained (Holme, 2007), though we have to assume an uneven distribution of the surface charge on the inner core surface. Such a difference of inner core rotation compared with that of the mantle is detected by the travel time of seismic waves, but the inner core rotation is faster than the mantle rotation (Richards & Li, 2007). Another explanation is that the axis of the inner core follows the rotation of the mantle but is slightly slower. Future elaborate researches will show whether this is the case or not.

2.4 Consideration of earthquakes and geomagnetism

If the present hypothesis is correct, geomagnetism reflects the rotation of the inner core or solar activities that directly couple with the inner core rotation through the magnetic field. This may partially explain the correlation between earthquakes and geomagnetism (Duma & Ruzhin, 2003).

2.5 Consideration of geomagnetic reversal

If the polarization of piezoelectricity changes its orientation, the geomagnetism is reversed (Tarduno, Cottrell, & Smirnov, 2007). During reversal, geomagnetism is weakened and eddy currents in the outer core that fix the inner core rotation axis so that it rotates with the mantle rotation are weakened. Therefore, the geomagnetic axis moves faster relative to the mantle axis compared to a stable period. The origin of magnetic fields of Jupiter and/or Saturn might be due to piezoelectricity as well, although the main constituents seem to be hydrogen and helium.

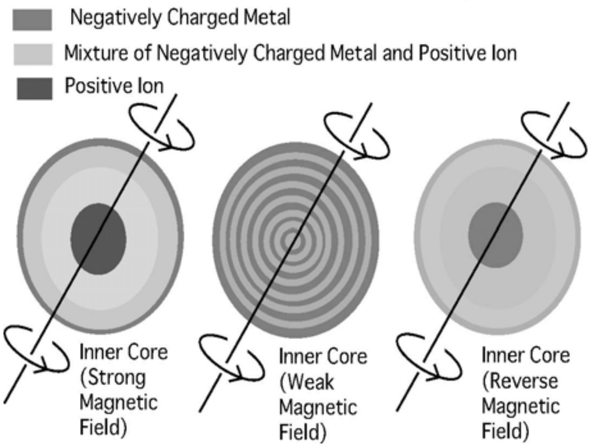

Figure 3. Schematic Process of Geomagnetic Reversal

3 CONCLUSION

This paper proposes a novel mechanism of geomagnetism, which assumes piezoelectricity of the inner core. The cause of piezoelectricity is partially explained using thermodynamic considerations. The mechanism explains why iron is separated into a mixture of iron positive ions and negatively charged iron metal. Piezoelectricity further requires the separation of positive iron ions and negatively charged iron metal by pressure. This may be explained by self-assembly or existence of nickel and sulfur in the inner core although the details are not clear at this time.

4 ACKNOWLEDGEMENTS

The author is indebted to Professor T. Kawakubo for his valuable discussions.

5 REFERENCES

Atkins, P. & Paula, J. (2002) *Atkins' Physical Chemistry* (7th edition), Chapters 2, 4 & 19, Oxford University Press, New York, USA.

Duma, G. & Ruzhin, K. (2003) Diurnal changes of earthquake activity and geomagnetic Sq-variations. *Natural Hazards and Earth System Sciences* 3(17). pp. 171-177.

Editorial Dept. of Jikkyo Shuppan (2005) *Science View: Chemical Data*, Jikkyo Shuppan, Tokyo, JP (in Japanese).

Holme, R. (2007) Westward Drift, in Gubbins, D. & Herrero-Bervera, E., (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*, Springer, Dordrecht, ND, pp. 993-995.

Kaminuma, K. (1988) *Peeping into the Earth*, Kodansha, Tokyo, JP, p. 55 (in Japanese).

Kittel, C. (1986) *Introduction to Solid State Physics* (6th edition), Chapter 7, John Wiley & Sons Inc., New York, USA.

Kraus, J.D. & Fleish, D.A. (1999) *Electromagnetism with Applications*, Chapter 7, McGraw-Hill, Singapore, SP.

Laj, C. et al., (1991) Geomagnetic reversal path, Nature, 351 447.

Lowes, F. (2007) Geomagnetic Dipole Field, in Gubbins, D. & Herrero-Bervera, E., (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*, Springer, Dordrecht, ND, pp. 310-311.

Richards, P.G.,& Li, A. (2007) Inner Core Rotation, in Gubbins, D. & Herrero-Bervera, E., (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*, Springer, Dordrecht, ND, pp. 423-425.

Stevenson, D.J. (2007) Nondynamo Theories, in Gubbins, D. & Herrero-Bervera, E., (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*, Springer, Dordrecht, ND, pp. 704-707.

Tarduno, J.A., Cottrell, R.D. & Smirnov, A.V. (2007) Paleointensity: Absolute Determinations Using Single Plageoclase Crystal, in Gubbins, D. & Herrero-Bervera, E., (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*, Springer, Dordrecht, ND, pp. 749-752.

Valet, J.P. & Herrero-Bervera, E. (2007) Geomagnetic reversal, Archives, in Gubbins, D. & Herrero-Bervera, E., (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*, Springer, Dordrecht, ND, pp. 339-346.

Whaler, K.A. (2007) Core Convection. in Gubbins, D. & Herrero-Bervera, E., (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*, Springer, Dordrecht, ND, pp. 80-88.