Geomagnetic Field Originated from Superconductors

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Abstraction

The geomagnetic field protects life on Earth from harmful radiation from space. However, the origin of the field is not well understood. The dynamo theory was proposed to be responsible for the formation of the field. However, the theory cannot explain the magnetic reversals observed throughout geological history. It cannot account for the magnetic fields of other celestial bodies, such as Uranus and Neptune. The unified theory for resistivity and superconductivity suggests that superconductors are common at high pressures. Due to the high pressure inside of Earth, superconductive substances likely exist under the mantle. Hence, a superconducting belt hypothesis was proposed to explain the origin of the geomagnetic field. Superconducting materials may float on the outer core. The rotation of the earth assembles the materials into a belt near the equator. The connected belt provides a superhighway for currents. Without resistance, currents loop indefinitely around the equator along the belt, creating the geomagnetic field. The conventions of the outer core disturb the superconducting belt, even break its continuity once for a while, which explains the phenomena of polar wandering and magnetic reversals. High-pressure superconductive substances may also exist inside of many other celestial bodies, and responsible for the origin of their magnetic fields.

Introduction

The Earth's magnetic field, also known as the geomagnetic field, is as essential to life as air, water and sunlight. It shields the earth by deflecting most of the solar wind, whose charged particles would otherwise strip away the ozone layer that protects the earth from harmful ultraviolet radiation. The magnetic field is becoming weaker: declined 10-15% over the last 150 years.[1-2] This process is accelerating. It is hard to imagine how we can survive without the geomagnetic field.

However, the physical origin of the geomagnetic field is not well understood. The dynamo model is a theory proposed to explain the geomagnetic field.[3-4] The model suggests that the magnetic field is induced and constantly maintained by the convection of liquid iron in the outer core. The heat exchange convection creates a feedback loop. The Coriolis effect due to the rotation of the earth deforms the feedback loop into spiral coils aligned along the rotation axis, Figure 1.[5] The magnetic field is mostly generated by the electric currents in the outer core with molten iron. As conducting fluid flows across an existing magnetic field, electric currents are induced according to magnetohydrodynamics equations, which in turn creates another magnetic field.[6-7] When this magnetic field reinforces the original magnetic field, a dynamo is created that sustains itself.

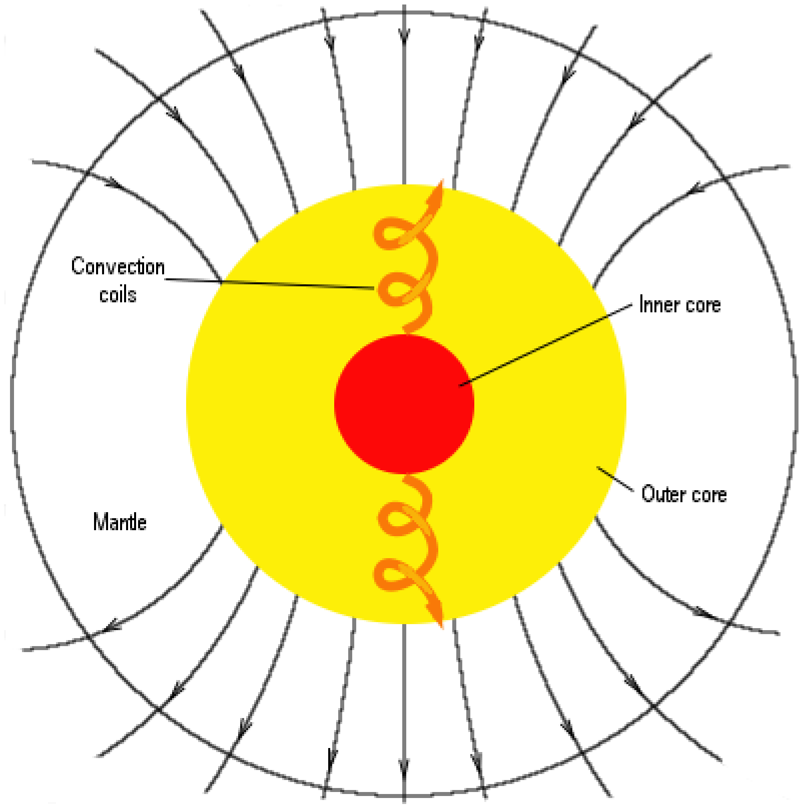

Figure 1: Dynamo model for geomagnetic field.

The dynamo model was initially proposed by Joseph Larmor in 1919.[3] It has been modified due to extensive studies and adapted lately according to magnetohydrodynamics equations. Magnetohydrodynamics was initiated by Hannes Alfvén[6] to explain the magnetic fields created by plasma, such as in the sun, which is much more dynamic in terms of velocity and viscosity than the outer core of Earth. Nevertheless, the model is still facing some challenges. It requires of a pre-existing magnetic field for the induction in the first place. The model cannot explain the magnetic fields observed on other celestial bodies, such as Uranus and Neptune. To address the problems, an alternative hypothesis was proposed in this study.

Superconducting Belt

A superconducting belt model is postulated to provide an alternative explanation for the origin of the geomagnetic field. A unified theory was recently developed for both resistivity and superconductivity.[8-9] The theory suggests that superconducting is a state observable for almost all materials, especially common at high pressures. As shown in the phase diagram, Figure 2, with enough pressure, superconductivity can be obtained for many substances.

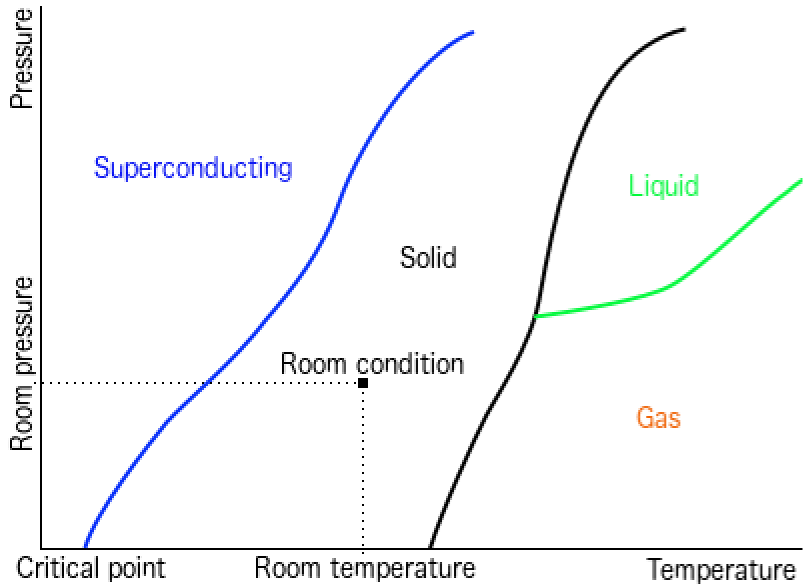

Figure 2, Phase diagram of superconductivity.

In fact, more and more high-temperature superconductors are discovered recently, usually at high pressures.[10-11] The pressures between lower mantle and inner core range from 136 to 360 gigapascals.[12-14] With such high pressures, superconductors likely exist under the mantle.

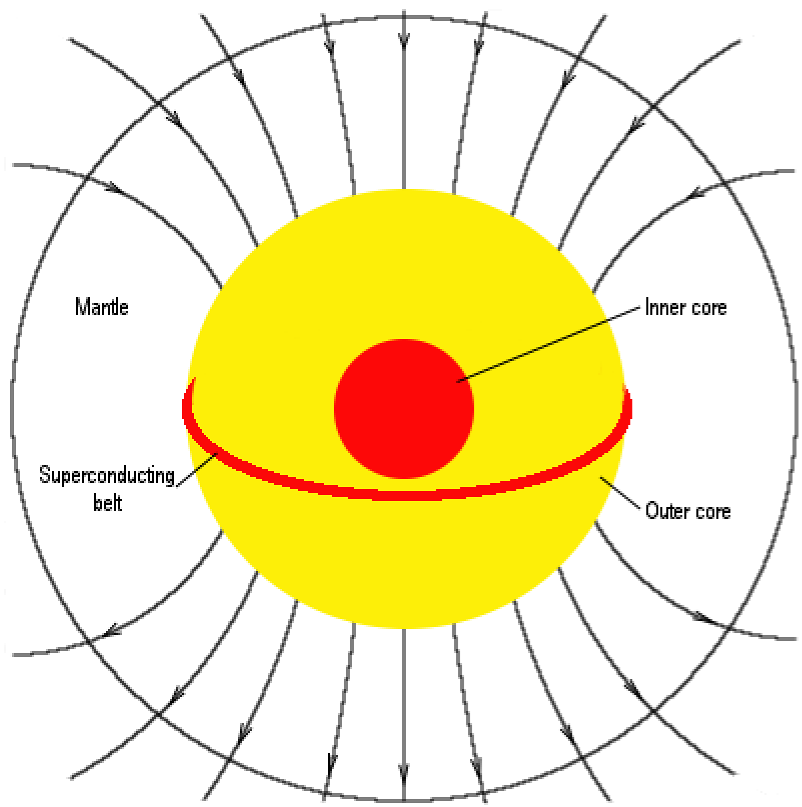

Figure 3, Superconducting belt model for geomagnetic field.

Superconducting materials may exist and float on the surface of the outer core and under the mantle. The rotation of the earth causes the materials accumulated near the equator, connecting into a belt, named **superconducting belt**. As enough of the materials assembled, the belt may connection into a loop around the equator, Figure 3. Without resistance, current may flow along the loop indefinitely. The large current loop surrounding the equator creates the geomagnetic field. The interaction between the convection of the outer core and this belt is responsible for geomagnetic reversals and polar wandering.

Geomagnetic Reversal

A geomagnetic reversal is an interchange of the positions between magnetic north and south. The geomagnetic field has alternated between periods of normal polarity, in which the predominant direction of the field was the same as the present direction, and reverse polarity, in which it was the opposite. The geomagnetic reversal history was well preserved on the seafloor as the ocean floor spreads from the mid-ocean ridge, Figure 4.[15] The direction of the magnetic field was frozen in the new ocean floor that was just formed in the mid-ocean ridge. Thus, the ocean floors recorded the magnetic reversal history like tapes. Studying the paleomagnetism, scientists were able to reconstruct the geomagnetic history.[16] Reversal occurrences are statistically random, lasting as little as 200 years. The latest brief reversal happened 41,000 years ago lasted only about 440 years. There have been 183 reversals over the last 83 million years.[17-19]

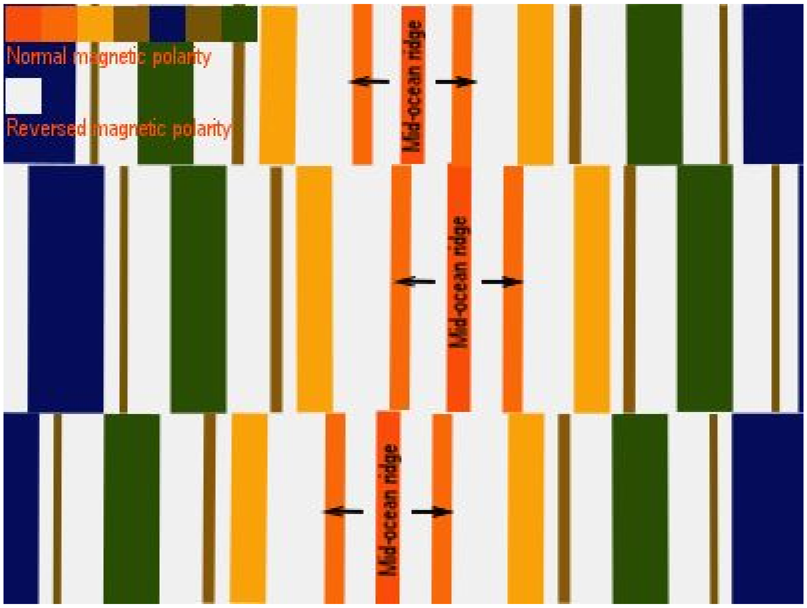

Figure 4: Magnetic reversal stripes on the seafloor.

Even though geomagnetic reversals have been observed in simulations using a computer model,[7] to explain the nature of the dynamic events still poses a challenge to the dynamo model. It is known that the rotation of the earth has been relatively stable, at least for the last few hundreds of million years, with gradual slowdown as a result of tidal effect.[20] Based on the dynamo model, the magnetic field is created by the convention coils in the outer core. To flip the generated magnetic field, the entire convection and coils must be reversed to the opposite direction. How can the convection coils flip back and forth in as short as 200 years? What's the force that can trigger such a drastic change inside the earth while still maintains its overall stability?

This phenomenon is addressed in superconducting belt model. Once for a while, the superconductor loop was broken by strikes of strong convection near the equator in the outer core. When the loop was broken, the current travelled in the superconducting highway had to shortcut through the non-superconducting materials between the two broken ends. The current was reduced quickly by the resistance. (This might create a short-term hotspot beneath the mantle.) If the belt was not able to reconnect quickly, the current would eventually disappear completely, so would the magnetic field. There might be a period of time without magnetic field on Earth. The rotation of the earth would eventually reassemble and reconnect the belt back again. After reconnection, the current would re-establish in the superconducting loop. This time, the current might be in the same direction as the previous time, or in the opposite direction, which resulted in a geomagnetic reversal.

The magnetic pole is not stationary and moves relative to the Earth's rotation axis. It has been observed that the geomagnetic pole is lately moving away from the Canadian Arctic toward Siberia.[21-22] The magnetic pole was also recognized migrating through geological time, known as polar wandering. This phenomenon is also explained with the superconducting belt. The convection in the outer core is able to push the belt and cause it deviate from the vicinity of equator. The process changes the average orientation of the plane formed by the belt, and therefore the orientation of the magnetic field it created.

Celestial Magnetic Field

Uranus and Neptune effective dipole centers are offset by 33% and 55% of their respective radii, Figure 5.[23-24] The magnetic dipole of Uranus is shifted from the center towards the south rotational pole by as much as one third of the planetary radius, while this shifting is even more in Neptune. The effective magnetic axes of Uranus and Neptune are tilted 59° and 47° from their respective rotational axes.[23]

Both Uranus and Neptune have a concentric interior structure.[25-28] Based on dynamo theory, the magnetic field is created by the convection coils, which should be aligned with rotational axes. The large offset and tilted magnetic axes make it hard for physicists to fit a working model in the dynamo theory.

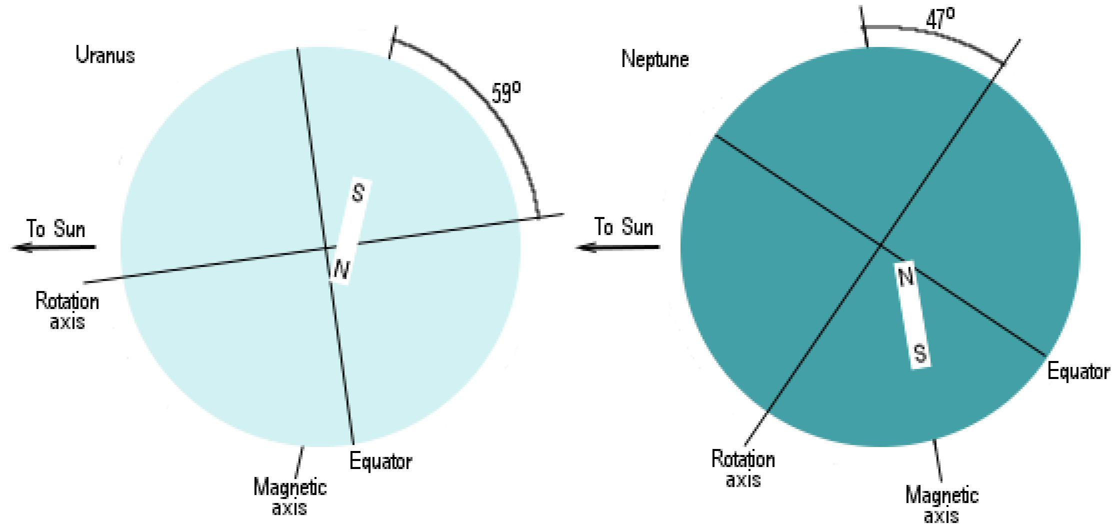

Figure 5: Magnetic fields of Uranus and Neptune measured by Voyager 2.

A magnetic field has been measured on Mercury.[29] Mercury size is about 14% of Earth.[30] It was thought that because of the small size, its core has cooled over the years. Mercury has a slow, 59-day-long rotation. These are some of the challenges to apply the dynamo model for Mercury.

As mentioned earlier, superconductors are common at high pressures and likely exist inside of celestial bodies. Superconductors are often observed at low temperatures and can be in any orientation as long as there is enough pressure. The existence of superconductors inside of large celestial bodies may provide the general solution for their magnetic fields. For instance, superconductors deep inside of the sun may produce the primary magnetic field. The magnetic fields created by plasma near the surface superimpose the internal field, making it more complex as observed.

Conclusions

To explain the origin of the geomagnetic field, the dynamo model faces many challenges. On the other hand, the superconducting model appears to be a better alternative. Based on the unified theory, superconductors are common at high pressures and likely exist under the mantle. A superconducting belt floating on the outer core near the equator may responsible for the origin of the geomagnetic field, which better explains the polar wandering and magnetic reversals. The existence of superconductors inside of celestial bodies may also provide the solution to their magnetic fields. Finally, it is not well understood how the current in the large superconducting loop/body is introduced. It may relate to solar activities. The initial current may be introduced by a solar wind. However, the nature of the interaction requires further studies.

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