



Science

STUDY OF PLANETARY MAGNETIC FIELDS

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Abstract

Magnetic fields are an important phenomenon in the solar system and beyond. Their causes are complex and have a variety of effects on their surroundings; they have become a critical tool for the exploration of solar system bodies. Magnetic fields play a very important role in the Sun. From sunspots to coronal heating, from solar ares to coronal mass ejections all these apparently diverse phenomena have magnetic fields as their ultimate cause. The study of the terrestrial dynamo is a difficult problem made more so by the inability to construct planetary-scale dynamos for laboratory study. However, understanding the nature of the matter comprising the Solar System is crucial for understanding the mechanism that generates Earth's geomagnetic field and the magnetic fields of other planets and satellites planetary dynamo models. In this study, in this study, classifications of planets are introduced. Development of planetary magnetism model is discussed. General concepts of the magnetic dynamo theory are introduced. Properties of planetary magnetic fields are presented and Earth crustal magnetic field is briefly discussed.

Keywords: Planetary Magnetic Fields; Planetary Dynamos; Planets, Magnetism; Solar System; History; Evolution.

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1. Introduction

Magnetic fields are an important phenomenon in the solar system and beyond. They are everywhere in the universe and have a variety of effects on their surroundings; In particular, they are often a characteristic of planets. Due to the fact that most of the planets in our solar system have substantial fields they have become both a critical target of the exploration and a critical tool for the exploration of solar system bodies.

A planetary magnetic field can be used to provide information from a distance about the internal structure of a body and its thermal evolution. The magnetic fields recorded and preserved in the crusts of planets also provide a window into the histories of the bodies. In many planets, the cause of this field is electrical currents deep within the body and its presence and behavior tells us something about the physical state and dynamics of the material deep within the planet. [1].

All planets in the solar system have or once had internally generated magnetic fields with the possible exception of Venus. The Moon also had its own magnetic field in the past, and Jupiter's satellite Ganymede has a magnetic field at present. Undoubtedly, other bodies in the solar system have generated magnetic fields in the past and possibly some other outer solar system objects have a magnetic field at present [2].

CLASSIFICATION OF THE PLANETS:

It is worth introducing the meaning of the three terms: Planet, revolution and rotation:

Planet: a few years ago there was not specific rule for what exactly a planet was. Since many things orbit a star, including comets and asteroids, some guidelines had been developed to help astronomers decide which objects get "planet" status and which get reclassified as other types of objects. This was mainly brought about by the discovery of several large objects in the outer solar system. In 2006, the International Astronomical Union (the group that defines astronomical standards) voted on the criterion for what makes a planet. Here is the final description – A celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighborhood around its orbit. Basically it has to be big enough to be round and dominates it location around the Sun. This definition rules out asteroids, Pluto and the other objects found in the area of Pluto, as well as comets (not big enough).

Revolution refers to the orbit of an object, as in "the Earth revolves around the Sun", or "The Moon revolves around the Earth". The term **rotation** refers to the spin of an object along an axis. "The Earth rotates once in approximately 24 hours", or "the rotation of Venus is in the opposite direction to that of the Earth".

Figure1. Shows the planets that are orbiting the Sun. The planets that orbit the Sun fall into three basic groups: **Terrestrial, Gas Giants and Ice Giants**. The number of known moons which orbit each planet is indicated in the parentheses [3, 4].

Terrestrial: Mercury (0) Venus (0) Earth (1) Mars (2)

Gas Giants: Jupiter (63) Saturn (66)

Ice Giants: Uranus (27) Neptune (14) and Pluto (3)

The Terrestrial planets are all made up largely of solid, rocky materials. They are all approximately the same size and density (approximately 4 to 5 times the density of water) With Mars being the least dense of the Terrestrial planets. For this reason, the terrestrial planets are believed to have higher concentrations of heavier elements than the Gas Giants planets. The Gas Giants planets are comprised of mainly low density gases. Their density is much less than the

Terrestrial planets (approximately 1 to 2 times that of water) but their mass is much more Jupiter and Saturn are composed mostly of the gases hydrogen and helium with an unknown interior. Ice Giants are planets with a good fraction of ice in their interiors.

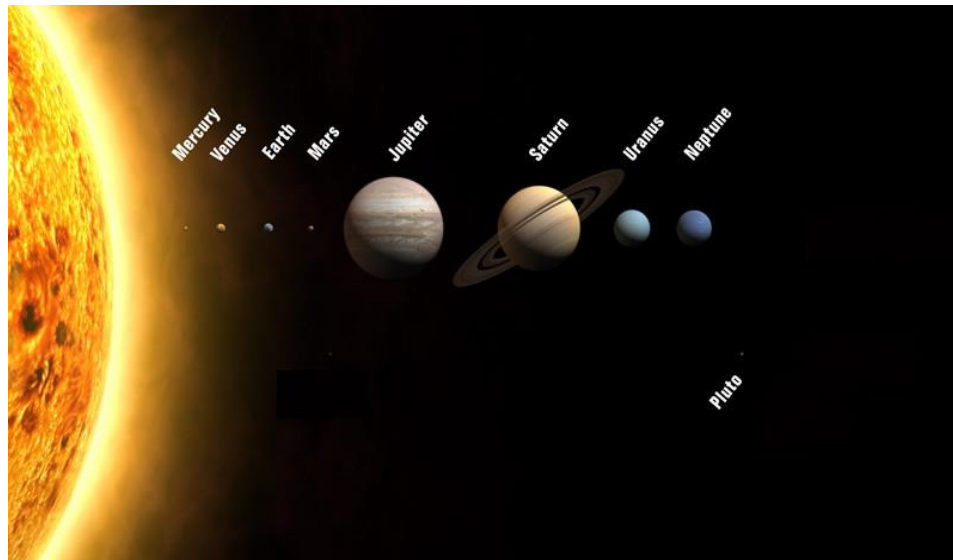


Figure1: Planets belong to our solar system [4].

Mercury: Earth and Mercury are the only planets in our system whose magnetic fields are generated by the movement of liquid metal at their cores. Mercury's magnetic field is 100 times weaker than Earth's. It's billions of years old and recently discovered data suggests that it was at one point as strong as Earth's.

Venus: While Venus does not have a magnetic field, likely because of its extremely slow rotation rate at about 243 Earth days, it's still protected from solar winds using a different type of magnetism. Its upper atmosphere, the ionosphere, interacts with solar particles and acts like a magnetic version of a comet's tail or a magneto tail. The magneto tail of Venus is shaped like the tentacle end of a jellyfish and faces away from the sun.

Earth: Earth's magnetic field is generated by liquid metal at the core and Earth's rapid rotation of 24 hours generates enough movement of the liquid to stimulate a magnetic field. The other planets in our solar system, except for Venus and Mars, all have magnetic fields or traces of magnetism that differ from Earth's in various ways.

Mars: Mars does not have a conventional magnetic field--one that is generated by movement at its core. Instead, Mars has powerful magnetic crustal fields that create fields of magnetism if situated correctly on the surface. To create the protective bubble, the magnetic lines have to connect at two points. Some of these magnetic domes are powerful enough to help maintain what is left of the vulnerable atmosphere on Mars.

Jupiter: Jupiter, the largest planet in our solar system, also has the largest magnetic field, generating a magnetosphere larger than the Sun. Its magnetic field is generated by its fast rotation. Unlike Earth, Jupiter's magnetic field is not generated from its core but by interactions

in its outer core, which consists of liquid metallic hydrogen. Jupiter's core is likely made of dense, molten liquid.

Saturn: Saturn is one of the only planets whose magnetic field lines up with its axis of rotation. Its field is generated by liquid metallic hydrogen, circulating a rocky core. Its core is heated by gravity pulling helium toward the core, and its rapid rotation.

Uranus: The magnetic field of Uranus is a little more complicated than the other planets. Uranus' magnetic field tilts dramatically and does not align with the rotation axis by about 59 degrees. The magnetic field also runs off center through the planet. Because the magnetic field is off center, in some places Uranus has two poles while elsewhere it has four. Uranus meets the two usual requirements for a magnetic field with a rotation period of about 18 Earth hours and electrically charged convection currents near the core. Scientists believe that Uranus's odd magnetic field could be caused by the electrical currents in the salty ocean within the planet.

Neptune: Neptune's magnetic field is generated within the planet's interior. Like Uranus, however, Neptune's magnetic field is significantly off-center and tilted away from its axis of rotation. Because the magnetic field line is offset, scientists believe that Neptune, like Uranus, has magnetic or electrical interactions occurring closer to the surface of the planet. If the magnetic field were generated at its core, the magnetic field would be more likely to go directly through the center of the planet as it does for Earth.

Of all of these natural magnets, the Earth's magnetic field is the most important to our existence. If Earth didn't have a magnetic field, we would be in trouble. The magnetic field protects us from harmful radiation from the Sun and helps keep our atmosphere from leaking into space [4].

2. Development of Planetary Magnetism Model

Most of the early discoveries into the nature of planetary magnetic fields were made by studying the most accessible magnetized object: the Earth, or the most powerful: the Sun. It has been known since ancient times that magnetized objects responded to some kind of force inherent in the Earth. Chinese legends suggest compasses were used in 2634 BC, and the first recorded use is found in a Chinese text published at the end of the 11th century. Attempts to explain the workings of the phenomenon began with William Gilbert in 1600; he developed a model of a magnetized Earth, in which he believed that the Earth rotated because it was magnetic. An astronomer Heinrich Schwabe, searching in 1826-1843 for the proposed planet Vulcan inside Mercury's orbit, discovered the 11-year sunspot cycle and noted that geomagnetic storms corresponded to sunspot maximums. [5,6].

Fifty years later, two parallel discoveries tied this phenomenon to the Earth. In 1907 Carl Stormer showed how energetic charged particles can be trapped in the field of a dipole or a magnetized sphere and, in 1908, Hale showed that sunspots were intensely magnetic by observing the Zeeman effect – the splitting of absorption lines in the spectrum of light under the influence of a strong magnetic field (Zeeman 1897) [7,8]. In 1919 Joseph Larmor introduced the fluid dynamo model when he proposed that sunspots, and the Sun's magnetic field itself, were the result of a self-sustaining dynamo in the plasma interior[9]. 250 years after Gilbert suggested

magnetism caused rotation, Blackett (1947) proposed the opposite: that all rotating bodies are magnetic, but this could not explain the Earth's historical pole reversals[10]. Finally, a decade later, Parker (1955) gave the fluid dynamo proposal that is essentially the model used today. Although various other mechanisms for generating the geomagnetic field have been proposed, only the dynamo concept is seriously considered today [11].

3. General Concepts of the Magnetic Dynamo Theory

The dynamo theory is a geophysical theory that explains the origin of Earth's main magnetic field in terms of a self-exciting (or self-sustaining) dynamo. In this dynamo mechanism, fluid motion in Earth's outer core moves conducting material (liquid iron) across an already existing weak magnetic field and generates an electric current. (Heat from radioactive decay in the core is thought to induce the convective motion.) The electric current, in turn, produces a magnetic field that also interacts with the fluid motion to create a secondary magnetic field. Together, the two fields are stronger than the original and lie essentially along the axis of Earth's rotation (see figure2).

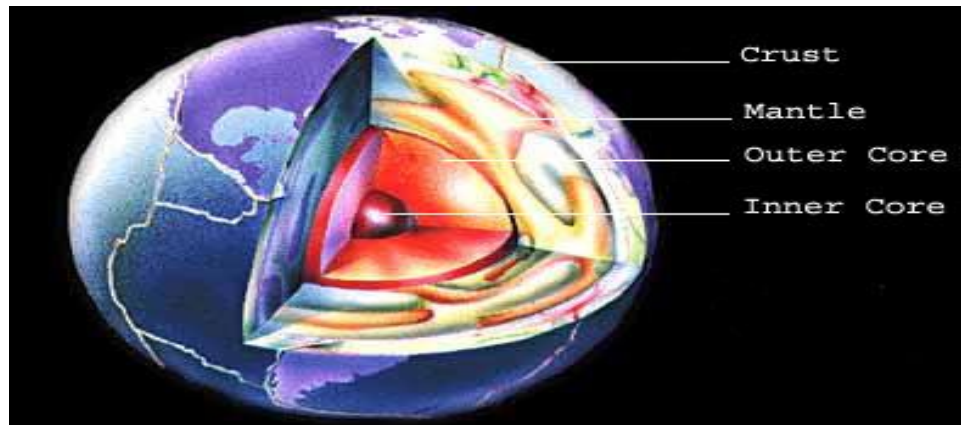


Figure2: Shows the inner and outer cores of the earth in association with the generation of the global magnetic field.[12]

The Earth's global magnetic field is generated in its metallic core, located nearly 3,000 kilometers beneath the planet's surface. The field has existed on Earth for at least 3.5 billion years and offers clues about how other planets, stars and celestial bodies may have formed. As scientists refine their understanding of how this field works in their ongoing probe of planetary history, one idea they use to explain this process is dynamo theory — the idea that a large dynamo, or magnetic field generator, exists within Earth's outer core, where liquid iron constantly moves as the planet cools.

This continuous motion creates electric currents as electrons move through the liquid. Through this process, the energy of the moving fluid is converted into a magnetic field that can be sustained for billions of years. Knowing that planetary bodies like Earth, the Moon, Mars, and even asteroids have, or once had, a magnetic field is crucial for understanding their history and internal structure. This is because the presence of a magnetic field inside a body reveals that it also likely formed a metallic core that generated that field. . Such a field is one of the few ways to remotely sense a metallic core buried so deep beneath a body's surface.[13,14]

If a fragment or rock from a planetary body is magnetized, this suggests that the body experienced large-scale melting in which heavier material sunk to the interior to form a metallic core and lighter material floated to the surface to create a rocky crust. This process gives a planet its history. Determining whether a planet generated a magnetic field in the past is not only important for inferring the presence of a core, but also may be important for learning about the origin of the planetary body and even the history of climate change for that body. Although Mars does not have a magnetic field generated by a core dynamo today, identification of magnetization in Martian rocks, indicates that Mars did have a strong global field billions of years ago. It appears that the disappearance of this early dynamo roughly coincided with the loss of Mars' early thick atmosphere and the transition from an early warm, wet climate to the planet's current cold and inhospitable conditions.

Magnetic traces within chunks from small, rocky objects called planetesimals were discovered that are believed to have slammed together to form the rocky planets 4.5 billion years ago. Planetesimals had previously been thought to be too small to have formed core dynamos. The finding suggests that sustaining a magnetic field like the one on Earth might not require a large, cooling core that constantly moves liquid and creates currents, but could also be somehow generated by the cores of smaller bodies like planetesimals some of which are only 160 kilometers wide.

Planetary magnetism therefore merits study from many perspectives, including that of understanding the physics of how dynamos work and what they imply about the past and present properties of the body containing the dynamo. The dynamo model believed that the magnetic field of a planet is a result of a rotating metallic liquid core (the motion of electrically charged particles/electric fields). Figure3. Shows the general concept of the dynamo model.

Planets do not have giant bar magnets in their cores, so what produces the magnetic field? A magnetic field can be produced by circulating electrical charges. A theory called the magnetic dynamo theory says that the magnetic field is produced by swirling motions of liquid conducting material in the planet interiors. Materials that can conduct electricity have some electrical charge that is free to move about. Such materials are called metallic and are not necessarily shiny solids like copper, aluminum, or iron. Jupiter and Saturn have a large amount of hydrogen that is compressed so much it forms a liquid. Some of that liquid hydrogen is in a state where some of the electrons are squeezed out of the atoms and are free to move around [15,16,17].

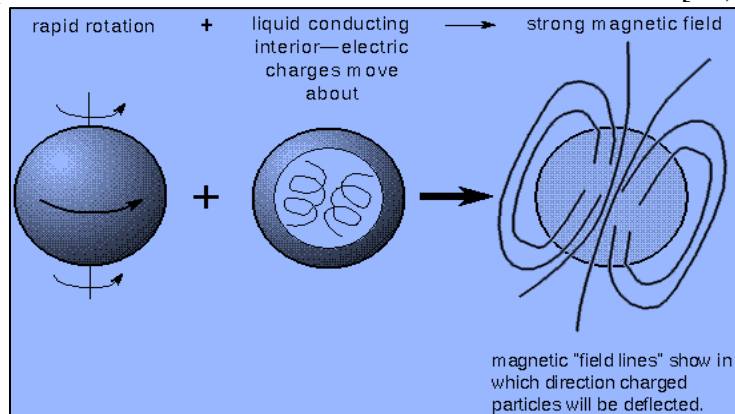


Figure3: shows in principle how the magnetic field is generated according to dynamo model[18].

A moving charge will produce a magnetic field. The liquid conducting material in a planet's interior can be made to swirl about if the planet is rotating quickly enough. The faster a planet rotates, the more the material gets stirred up and, therefore, the stronger the generated magnetic field. In Jupiter and Saturn the gravitational compression is great enough to squeeze electrons out of the hydrogen atoms so they move easily in the liquid and conduct electricity- liquid 'metallic' hydrogen (see figure4).

If the liquid interior becomes solid or if the rotation slows down, the magnetic field will weaken. So in summary what a planet needs in order to produce a strong magnetic field are (1) a liquid conducting (metallic) interior and (2) rapid rotation to get the conducting material moving about.

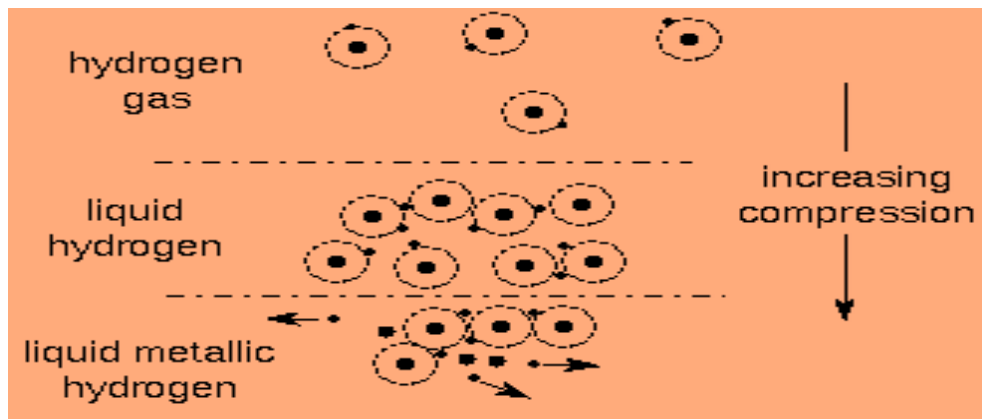


Figure4: Production of liquid metallic hydrogen[18].

Gaps in our knowledge of planetary properties place serious limitations on the ability to understand the variety of planetary dynamos found in our solar system. It can be said that the sources of the planets magnetic fields also vary. Most planetary magnetic fields are produced by the dynamo effects. Other magnetic fields (weak remnant ferromagnetism) are shadows of their former glory. Weak *remnant ferromagnetism* may exist if charges are bound to atoms and locked into a specific alignment. This type of ferromagnetism is generally weak and not long lasting (it decays over time). Another possible source of magnetic fields is an object that has a conducting surface layer picking up a magnetic field through interactions of charged particles from the Sun. This interaction could result in a weak and short term magnetic field.

Observations of magnetic fields can be done by observations of particles trapped in the field or through the use of instruments such as a magnetometer, or a compass. Another way to observe a magnetic field is to see the display of aurora features. This varies with the strength of the field and the amount of material being given off by the Sun. Measurement of the parameters such as the mass, size, temperature, magnetic field properties, and estimate the composition (based upon the location in the solar system at formation) may not provide precise information about a planet's interior.

It is true that most of the information has to be combined into a physical model that would predict how all of these features would interact or be visible on the surface, but even at this time there is a great deal of uncertainty about many objects. In a few cases information can be obtained from the interior of planets through seismic events, such as volcanic eruptions,

earthquakes, moon-quakes and objects impacts. It is theoretically possible to use oscillations in the gas and ice giants to model their internal structures, since they should wiggle in a certain way based upon their internal composition. However such oscillations are very low level and not easy to observe at this time.

However, there are systematic trends of properties within the Solar System that are clues about the planet formation process: Planets all orbit the Sun in the same west to east sense that both the Sun and Earth rotate in (see figure5) [19,20].

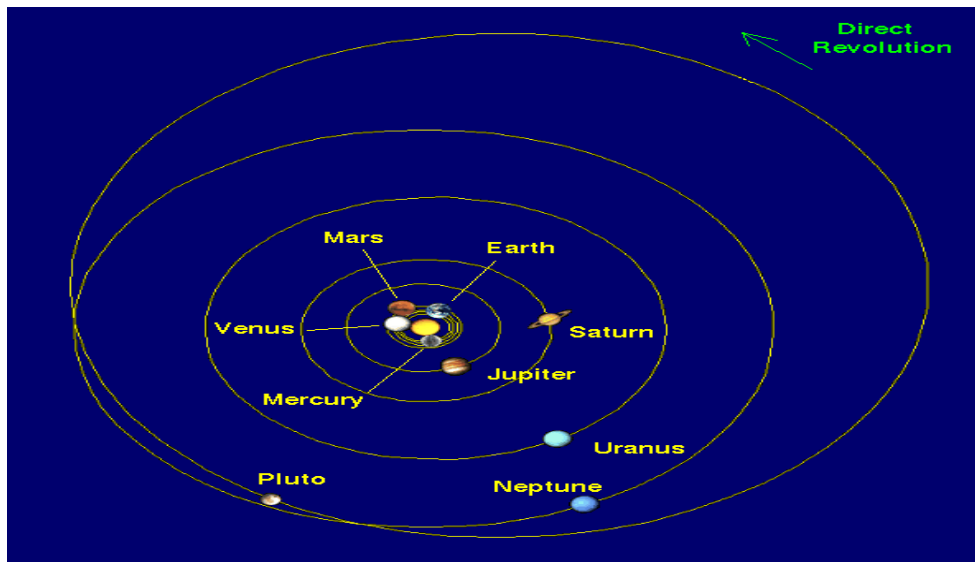


Figure5: shows that all planets orbit the sun in the same west to east sense that both Sun and Earth rotate in.

4. Properties of Planetary Magnetic Fields

Magnetic fields in planets can be broadly divided into two categories: remanent fields and intrinsic fields, plus an intermediate form in which a field is induced by an external force. A remanent field simply indicates that an object was once magnetized and still retains the magnetism, like a traditional bar magnet. A remanent field has three requirements: (1) A material capable of holding a magnetic field; (2) An initial force to cause the magnetization; and (3) A temperature sustained below the Curie Point: the temperature above which a given material loses its remnant magnetism. Remanent fields are stable, and are not a good model for a field whose polarity is seen to change.

An intrinsic field is an active phenomenon resulting from some property of the object. Most planetary magnetic fields are self-sustaining intrinsic fields generated by an internal dynamo, following the model first proposed by Parker (1955) and later modified to become Kinematic Dynamo Theory (Fortes 1997). This model requires that a planet have (1) A molten outer core of a conducting material; (2) convective motion within the molten core; and (3) an energy source to power the convective motion.

If a system with some of the conditions necessary for a dynamo is imbedded in a time-varying magnetic field (such as of a parent planet or the passing solar wind), the dynamo may still function, generating a field that is said to be induced by the ambient field. The interaction of the solar wind and a planetary magnetosphere is equivalent to a dynamo, modulated by the changes in the plasma flow of the solar wind see figure6. Planets which generate magnetic fields in their interiors, such as Earth, Mercury, Jupiter and Saturn, are surrounded by invisible magnetospheres – Their magnetic fields deflect the charged particles of the solar wind (electrons and protons) as they stream away from the Sun. This deflection creates a magnetosphere – a protective "bubble" around the planet – which ends in an elongated magneto tail on the lee side of the magnetosphere.

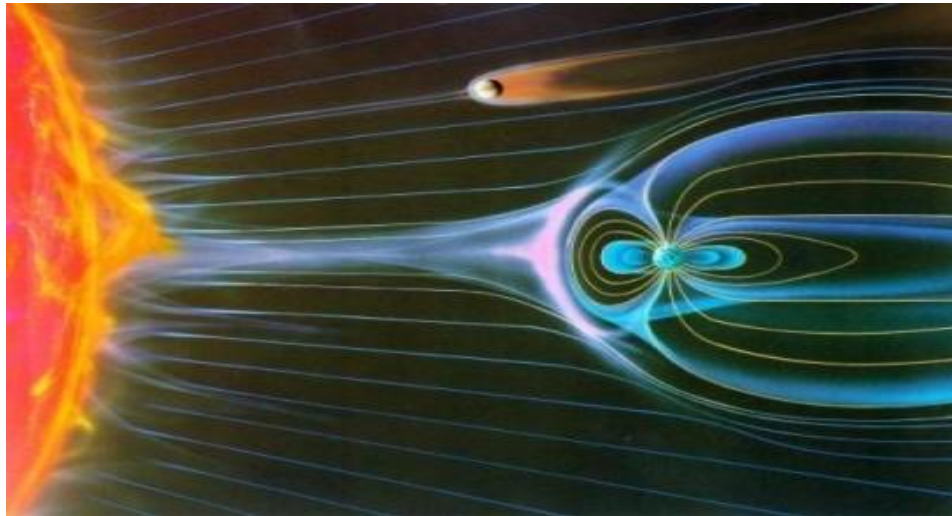


Figure 6: Artist's impression showing how the solar wind shapes the magnetospheres of Venus (shown with a brown tail, closer to the Sun) and Earth (shown in blue).

As on Earth, solar ultraviolet radiation removes electrons from the atoms and molecules in the upper atmosphere, creating a region of electrically charged gas known as the ionosphere. This ionized layer interacts with the solar wind and the magnetic field carried by the solar wind. During the continuous battle with the solar wind, this region of the upper atmosphere is able to slow and divert the flow of particles around the planet, creating a magnetosphere, shaped rather like a comet's tail, on the lee side of the planet. All planets which have internal magnetic field have as well magnetospheres. The importance of magnetospheres. To planets cannot be underestimated and this topic will be included in future study [21,22].

Since the first planet studied closely – the Earth – has its dipole nearly aligned with its axis of rotation, it seems reasonable to assume that there is some reason this should be the case; and to ask why the dipole is not, in fact, precisely aligned with the rotation axis. It turns out the orientation of the dipole need not be related to the axis of rotation and that the angle between the two is more a function of the nature of the internal dynamo. Dipole magnets also have “North” and “South” poles, and not all of the planets have the same pole pointing up or down. Their orientation is coincidental since they reverse periodically. Magnetic fields behave as though they are anchored to the interior of the planet, and rotate at the speed at which the planet rotates see figure7.

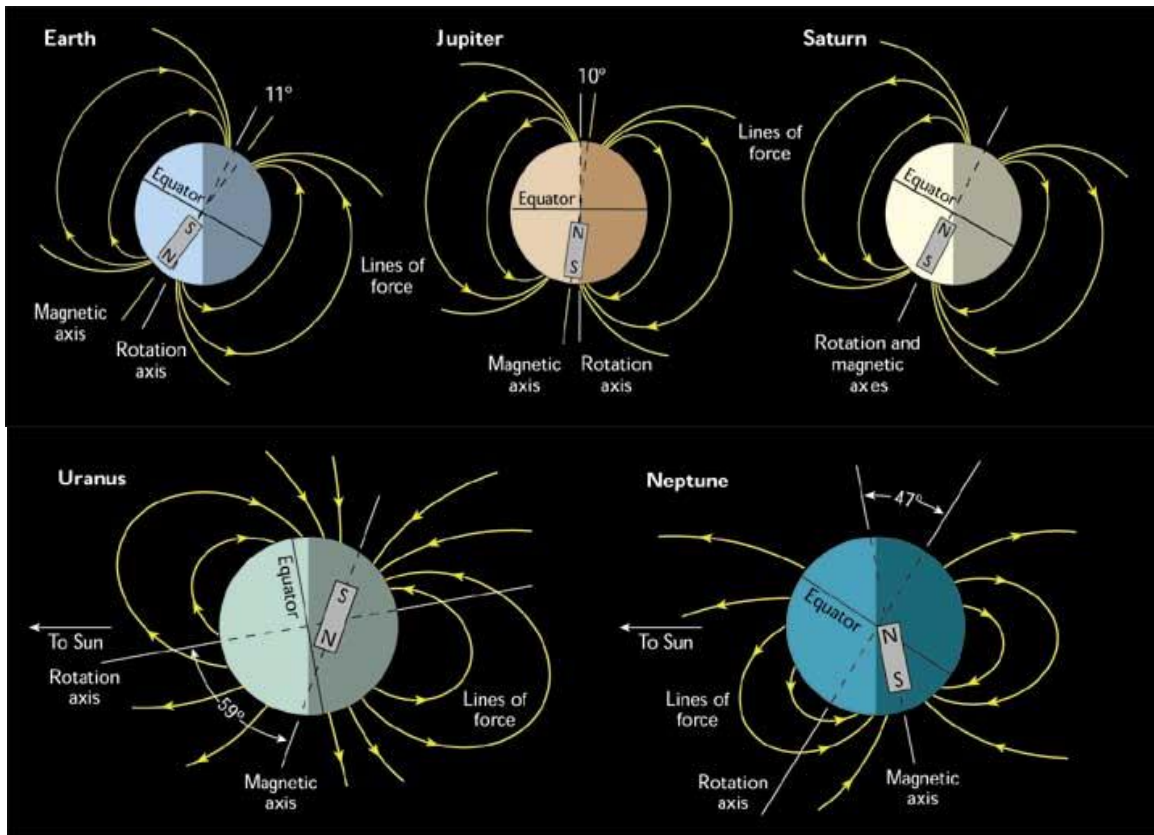


Figure7: Earth, Jupiter and Saturn have fields that are oriented within ~10 degrees of the spin axis. Uranus and Neptune, have highly tilted magnetic fields that are strongly offset.

Typically planets and moons which rotate very slowly do not have an appreciable magnetic field. This is true of the Moon and of Venus. And although Mars rotates at the same rate as the Earth, it possesses no appreciable magnetic field. This may be because the core is no longer liquid. On the other hand, the larger gas planets have magnetic fields comparable to, or larger than Earth's. This is probably because of their rapid rate of rotation.

Understanding the nature of the matter comprising the Solar System is crucial for understanding the mechanism that generates Earth's geomagnetic field and the magnetic fields of other planets and satellites. The most powerful magnets on Earth have a magnetic field strength near 160 000 Gauss= 16 Tesla [1 Tesla = 10^4 Gauss]. The study of only the planets (looking at only 0.2% of the material in the solar system) is rather limited when viewed in terms of how significant they are in the solar system.

Practically all of the material in the solar system is found in the Sun (99.8% of the mass). After that Jupiter is the largest thing (with 0.1% of the mass), then Saturn (0.03% of the mass), and Uranus and Neptune together make up only 0.01%. So all of the material on the Earth and the other 3 small planets, all of the asteroids, etc., make up only 0.001% of the mass of the solar system [23]. Table1 summarizes relevant information for the planets in the solar system.

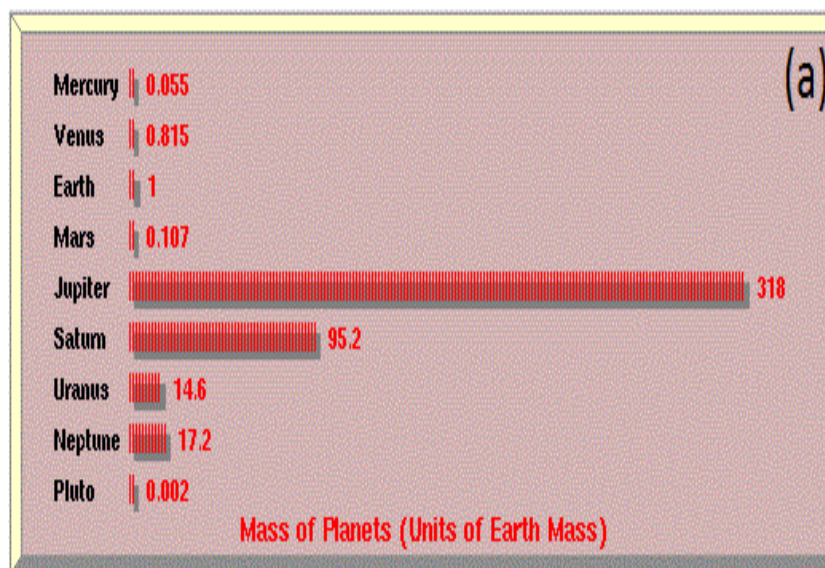
Table1: Some physical characteristic of planets in the solar system.

Planet	Distance (in AU)*	Radius (Km)	Field Strength (Gauss)**	Mass 10^{24} Kg	Density g/cm^3	Rotation (E-Days)	Rev/ orbit
Sun	0.0	695,510	1-2	1.99E+30	1.41	27.00	-
Venus	0.7	6052	0.00	4.87	5.24	243.02	224.7d
Earth	1.0	6371	0.31	5.97	5.52	1.00	365.2d
Mars	1.6	3390	0.00	0.64	3.94	1.03	686.9d
Jupiter	5.2	69911	4.25	1900	1.33	0.41	11.86 y
Saturn	10.0	58232	0.21	570	0.69	0.44	29.46 y
Uranus	19.6	25362	0.23	87	1.27	0.72	84.01 y
Neptune	38.8	24624	0.14	100	1.64	0.67	164.1 y
(Pluto)	77.2	1187	Unknown	0.01303	2.00	6.39	248.5 y

*(1 A.U. is mean distance from Earth to Sun: 149.6 million km)

**Magnetic fields at the surface of the planets.

The physical properties of the planets vary in a systematic fashion as a function of distance from the Sun [but note that Pluto is somewhat of an exception to this, (see figure8). [24].



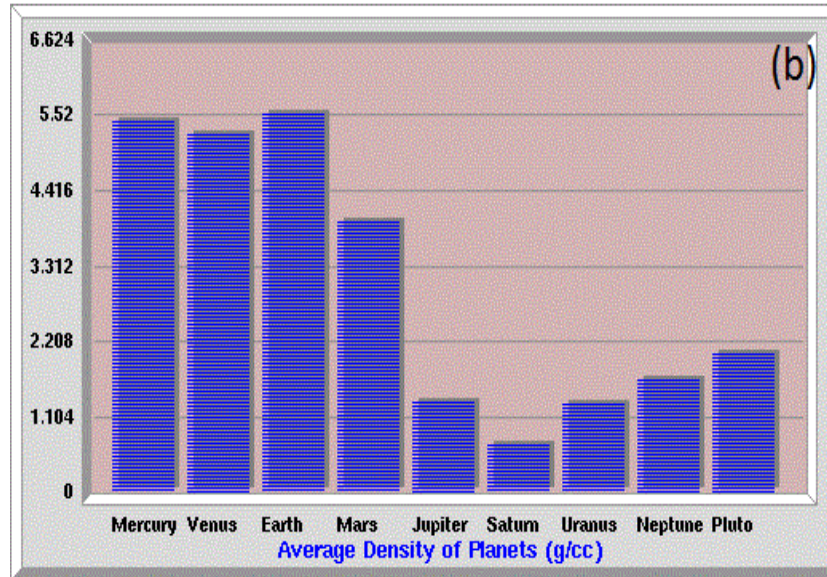


Figure8: (a) shows the variation of physical properties of planets as a function of distance from the sun. (b) shows average density of planets (g/cm³)

Figure9. Shows the Sun's magnetic field lines. It can be seen from the figure that the surface of the sun is full of movement. In the 1950s, astronomers got their first glimpse of 'dancing' solar material, which emits light only in wavelengths invisible to our eyes. The figure has also revealed how the sun's magnetism changes in response to the constant movement. It suggests that 'bright spots' in the solar atmosphere could provide a marker for the sun's mysterious magnetic field.

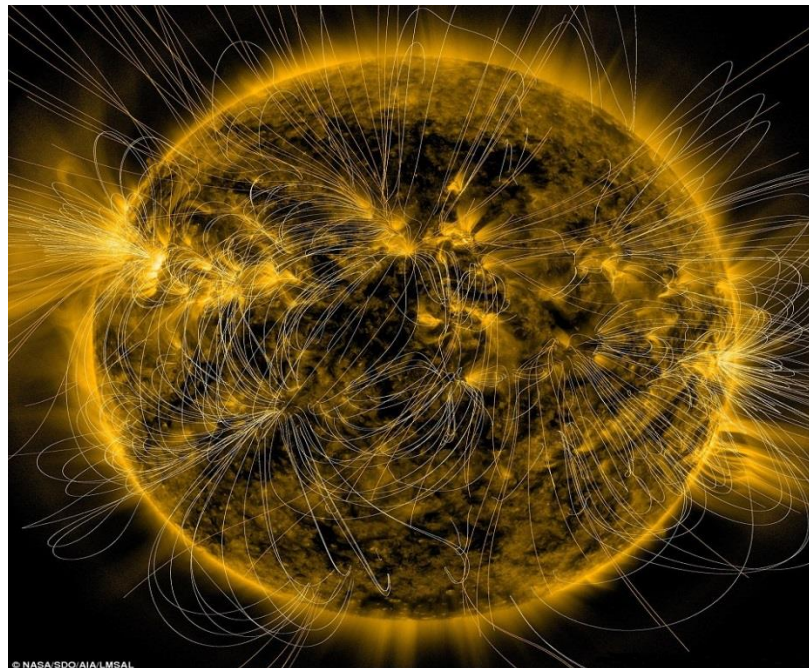


Figure 9: shows the Sun's magnetic fields and the ways the sun's magnetism changes in response to the movement on and inside the sun. Magnetic fields (white) are densest near the bright spots visible on the sun and many of the field lines link one active region to another[25].

While the Sun is not a planet, it is an important part of the solar system. Of course it has the most mass in the solar system, but it also interacts in various ways with the planets: Gravitational (dictates the motion of objects in the solar system), Radiative (the energy from the Sun impacts all planets in a variety of ways, including seasonal effects, and can even alter the motion of objects), Particles/rays (the influence of the solar winds on planetary magnetic fields is important for planetary development and can interact with surfaces resulting in chemical reactions), The Formation history (the formation of the solar system is tied up with the formation of the Sun), and The Ultimate demise (when the Sun dies, so does our solar system).

5. Earth Crustal Magnetic Field

The field arising from magnetic materials in the Earth's crust varies on all spatial scales and is often referred to as the anomaly field. A knowledge of the crustal magnetic field is often very valuable as a geophysical exploration tool for determining the local geology. The magnetic field at or near the surface of the Earth is a combination of Earth's magnetic field and fields of external (solar) origin. The Earth's magnetic field is itself a superposition of the field generated by the geodynamo in the liquid outer core (main field) and the field of magnetized rocks in the crust and upper mantle. The main field dominates the long wavelengths, down to about 3000 km, whereas the crustal field dominates at wavelengths smaller than 2500 km. Many different applications utilize Earth's magnetic field, whether for navigation, resource evaluation, or research. Figure10 shows the Earth's Crustal Magnetic field map.

The anomalies seen at mid-ocean spreading ridges are of particular interest. At these locations molten mantle comes to the surface and solidifies to form new oceanic crust,

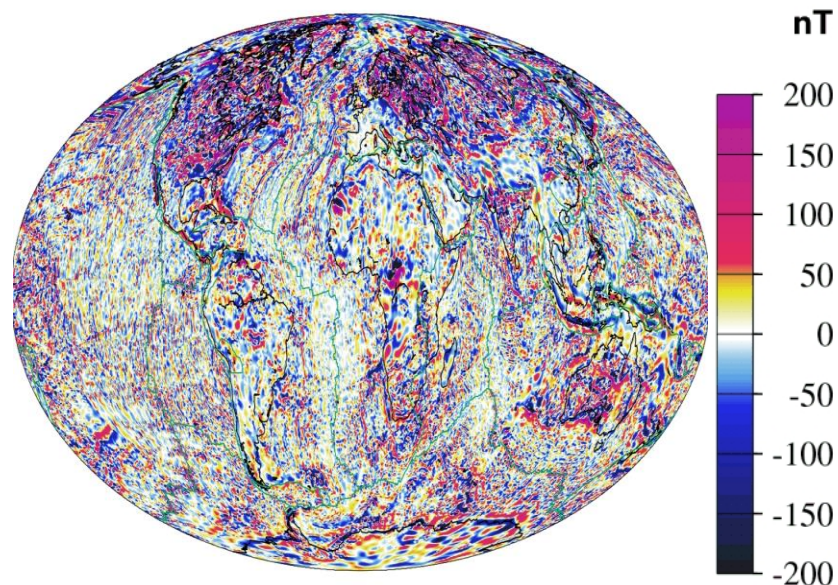


Figure10: Earth's Crustal Magnetic field map.[26]

Preserving in it the strength and direction of the contemporary ambient magnetic field. As new material is extruded, the existing crust is pushed away on either side of the ridge, with the direction of the ambient magnetic field at time of formation frozen into it. Marine and aeromagnetic surveys reveal a series of stripes in the total intensity anomalies which run parallel

to and symmetrically about the central ridge and these are interpreted as alternating blocks of normal and reversely magnetized oceanic crust.

Studies of the geomagnetic field have a long history, in particular because of its importance for navigation. The geomagnetic field and its variations over time are our most direct ways to study the dynamics of the core. The variations with time of the geomagnetic field, the secular variations, are the basis for the science of paleomagnetism and the concept of plate tectonics. It was also known early on that the field was not constant in time, and the secular variation is well recorded so that a very useful historical record of the variations in strength and, in particular, in direction is available for research. This discovery of a crude tape recorder of the Earth's magnetic field and its reversals was invaluable to the theory of plate tectonics developed in the 1960s. Magnetism also plays a major role in exploration geophysics in the search for ore deposits [26].

6. Conclusion

Observations from planetary spacecraft missions have demonstrated a spectrum of dynamo behavior in planets. Since magnetic fields are generated in a planet's deep interior and extend beyond the surface where they are observable, magnetic fields can act as important probes of planetary interior structure, evolution, and dynamics. Therefore, no wonder that one of the most fundamental questions of solar physics is: how are the magnetic fields of the Sun and all astronomical bodies generated?

The dynamo mechanism, thought to be responsible for generating the geomagnetic field, operates as a magnetic amplifier wherein, beginning with a small magnetic field, the combined motions of an electrically conducting fluid, driven by convection in a rotating system, amplify and maintain a more-or-less stable, much, much larger magnetic field. Current planetary dynamo models have opened a window into planetary cores, providing insights into core fluid flows, convective stability and thermal evolution.

Understanding the nature of the matter comprising the Solar System is crucial for understanding the mechanism that generates Earth's geomagnetic field and the magnetic fields of other planets. Understanding the planetary dynamo models therefore, not only investigate the magnetic field generation process, but also tell us about regions of the planet difficult to study with other means.

The study of the terrestrial dynamo is a difficult problem made more so by the inability to construct planetary-scale dynamos for laboratory study. However, much work is still needed before the planetary dynamo process is fully understood and full advantage be taken of the implications of planetary magnetic field observations. The main improvements needed are better observational and experimental data on magnetic fields and in numerical modeling methods and computational power about interior structure and dynamics of the solar system.

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