Magnetosphere Formation of A Tidally Locked Planet or Satellite

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Short Communication

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ABSTRACT

Magnetosphere is the part of a planet that contains the magnetic field lines that prevent harmful solar winds that can wipe out any kind of life by destroying the atmosphere of the planet. Some tidally locked planets were thought to lack this magnetosphere as they don't have convection currents in their core, but recent studies of exo-planets have revealed that due to tidal heating, core of planets can melt. If the temperature inside the core excides a certain threshold then due to ionization the core can get partially charged producing a changing electric field which in turn can produce magnetic field.

INTRODUCTION

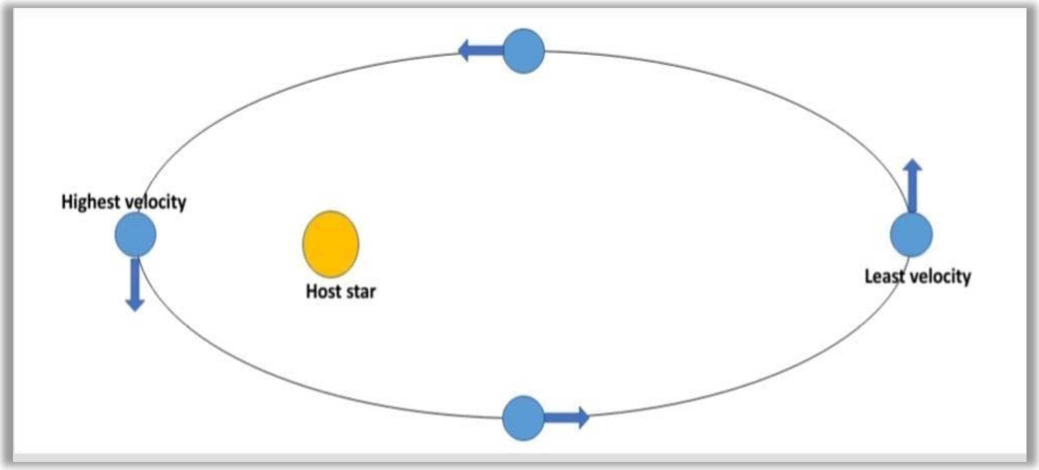
Magnetosphere can serve as the line of defence for any planet as it prevents harmful solar winds to destroy the atmosphere and wiping out all the life forms that might be present on the planet. It was long thought that magnetic field is a result of convection currents produced by the rotation of a planet and a tidally locked planet cannot possess such kind of defence as the its one side is permanently faces it's host star and one side always remains in dark, in other words it doesn't show rotational motion about its axis. But under certain circumstances it can possess magnetic field although much smaller in magnitude as compared to Earth's magnetic field [1].

Formation of magnetosphere

For a tidally locked planet or satellite to have magnetic field, it must fulfil some conditions [2]. Firstly, it must be in a highly eccentric orbit around its host star and secondly, the perihelion must be much closer so as to achieve high velocity that is necessary for a changing electric field.

We will consider four points on the orbital path of the planet, one as the aphelion, second as the perihelion and two other diametrically opposite points in between the points mentioned above as shown in Figure 1.

Figure 1. Here blue arrows denote the direction of motion of the planet.



As shown in Figure 1, when the planet is nearer to its star then its velocity is higher as compared to when it is further away at aphelion. When it orbits by this orbital path then tidal forces act on the body causing it to expand and contract diametrically which causes high heat generation within the planet's core that melts the core. As of now it is pretty much clear that most of the terrestrial planets have a core that comprises mostly of iron, nickel and some amount of other heavy elements such as gold, silver.

In order to the formation of magnetic fields the iron in the core must be in its ionized form then only it would create a magnetic field. The ionization potential of iron is nearly 7.9024eV or roughly $1.2\times10^{-18}\ joules$ which is pretty high but if the temperature of core is high enough then it may ionize iron at least to some extent. The temperature required for ionization of iron can be calculated as follows:

Since the ionization energy is known, we can apply energy-temperature relation to calculate required temperature,

$$1.2\times10^{-18} = \frac{3}{2}k_B T \text{...........} Equation(1.1)$$

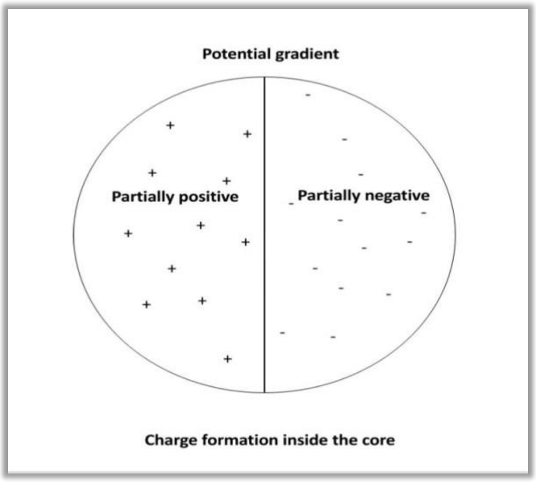
Hence,

$$T = 5.797\times10^{-4} K \text{............} Equation(1.2)$$

Where T is temperature required and kB is the Boltzmann constant. So in order to the formation of magnetic field the temperature of the core although very high but can be achieved.

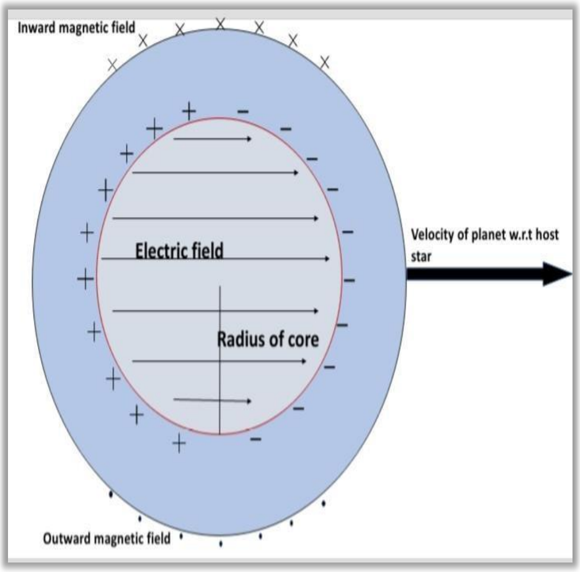
When this high temperature ionizes the iron atoms then due to release of electrons iron atoms become positively charged. Now as the planet moves the core becomes partially charged due to the fact that these iron ions are heavier than electrons, hence it forms a layer on iron ions, in this way part of the core becomes negatively charged and part of it becomes positively charged as shown in Figure 2.

Figure 2. Due to motion core separation of charges takes place.



When this charge separation takes place, there is a generation of electric field in the direction of left to right. Also, this electric field changes due to the planet's changing velocity from point to points. And as per Ampere-Maxwell law this varying electric field would generate magnetic field around the planet [3]. For this magnetic field to be able to deflect solar winds the planet must have proportionally high rotational velocity and eccentricity. The magnetic field produced by this type of a planet decays in the direction of electric field and is weaker as we move in the direction of the planet's motion [4-6]. A depiction of this is shown in Figure 3.

Figure 3. Direction of magnetic field, electric field and velocity of the planet.



The intensity of magnetic field can also be predicted by Ampere-Maxwell equation. Since,

$$\oint_c b.dl = \mu_0 \left(I_{enc} + \varepsilon_0 \frac{d}{dt} \int_s e.\hat{n}da \right) ....Equation(1.3)$$

Where b is the magnetic field, e is electric field, n is the area vector, μ_o is magnetic permeability of free space and ε_o is the electric permittivity of free space.

Solving this equation we get:

$$b = \frac{\mu_0 I_{enc}}{2\pi R_B} + \frac{\varepsilon_0 \mu_0 R_c^{\ 2}}{2R_B} \left(\frac{de}{dt} \right) ....Equation(1.4)$$

Where, R_B is the distance up to which magnetic field strength can be measured; R_c is the radius of core which are constants. This equation provides us the magnetic field strength of a tidally locked planet. As seen in the equation, the magnetic field strength of the planet is directly proportional to the square of radius of the planet's core, the bigger the percent volume occupied by the core with respect to complete planet the greater would be magnetic field strength.

CONCLUSIONS

The conclusions that can be drawn from this are that unlike common misconception that tidally locked planets do not possess a magnetic field although they might possess a magnetic field. The magnetic field produced by charge separation is subject to degeneracy of electrons; due to this the modified equation may contain a term expressing its effect. As some tidally locked planets can have magnetic fields therefore they can also have an atmosphere but one should note that due being in close proximity of their host stars, this planets are less likely to harness life as we know it. But this also opens many gates regarding how planets generate magnetic field.

ETHICAL STATEMENT

This manuscript is not published or under consideration in any other journal. And the author is aware of the publication policies of the journal.

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AUTHOR CONTRIBUTIONS

This research was done by Deepanshu Chouhan from writing the manuscript to submitting the work.

DATA AVAILABILITY STATEMENT

All the data used to support this research is available on Google and can be accessed. Data generated for manuscript can be provided if needed. The data for figures was generated by the author himself.

CONFLICT OF INTEREST

As of my consent, there is no conflict of interest.

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