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Analysis of Gyro-Period of Space Plasma Wave Using Interplanetary Magnetic Field Data

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Abstract: *Gyro-period is the time it takes the plasma particle (electron and ion) to complete one revolution. This paper has explained how variation of magnetic field affects the gyro-period of plasma wave. Relationship between gyro-period and inverse of magnetic field for the year 2001 was determined, including their monthly and seasonal relationships. The result shows that electrons have very small gyro-period compared to ion, making them to move faster than the ion in a stream of plasma. It also shows that the gyro-period of plasma wave varies with the magnetic field and this variation has no effect on our yearly seasonal changes on planet earth.*

Keywords: *Interplanetary magnetic field (IMF), gyro-period, gyro-frequency, gyro-radius, plasma and solar wind*

I. Introduction

Some observations in the earth atmosphere and other terrestrial planet such as global warming have been difficult to account for. This effect has been traced to be as a result of penetration of space plasma particles into the planet. Understanding the gyro-period of this plasma particle in the presence of interplanetary magnetic field will help understand the nature of this particles and how fast this particles can move to create such possibility of impact.

As the temperature of a solid is increased, a point reaches when the phase changes to liquid. Further increase in temperature leads to another phase transition from liquid to gas. As the temperature increases, then finally the bonds binding electrons and ions are broken and the gas becomes electrically conducting plasma (Howard, 2002).

Solar wind is the continuous ejection of plasma from the sun's surface into and through the interplanetary space. Thus, our sun is an entirely ionized ball of plasma. The particles ejected from the sun follows a spiral path (helical orbit) around the magnetic field. Ions rotate in left hand sense about the magnetic field (i.e. clock wise) while the electrons rotate in a right hand sense (anti clockwise). The path produced by the ion is larger than that of electrons. As a result of the particles gyration, we can talk of gyro-frequency (cyclotron frequency), gyro-period, and gyro-radius.

Plasma can be loosely described as an electrically neutral medium of equal positive and negative particles (i.e. the overall net charge of plasma is roughly zero). When the charges move they generate electrical currents with magnetic fields, and as a result, they are affected by each other's fields (Sturrock *et al*, 1994).

This paper deals with study of the behaviour of both the electron and ion under the influence of the sun magnetic field that extends into the interplanetary space and is referred to as the interplanetary magnetic field (IMF). It takes into consideration the analysis of the time it takes an electron or an ion to move around the magnetic field and compares the gyro period of these particles. This consideration is aimed at giving more understanding of how fast a particle could move around the IMF which has a direct link with the planetary bodies. This paper also seeks to give an understanding that can lead to more research into the effect of these particles speed on the planetary bodies in terms of mass, momentum and energy transfer.

From the study of the trajectory of these particles, the parallel and perpendicular components of the velocity describe a helicoidal motion. This follows the helical sweep of the IMF. Such orientation of the IMF from the sun towards the planetary bodies leads to a possible northward and southward IMF. Since the geomagnetic field is directed from south to north, southward IMF can easily merge with the northward geomagnetic field leading to a transfer of mass, momentum, and energy.

Also, this paper seeks to find the behaviour of plasma gyro-period in different months and seasons. All through this work, ion represents positive charge except stated otherwise.

II. The Sun's Atmosphere

The Photosphere

This is the lowest and visible surface of the sun, with a temperature of 6000K. It is a thin skin only about 500km that emits most of the Sun's light and has a density of $10^{23} m^{-3}$ (kivelson, 1995).

The Chromosphere

Just above the photosphere lies the chromosphere, with a density of $10^{17}m^{-3}$ (kivelson, 1995). It extends to a height of about 2500km above the photosphere. The temperature of the chromosphere begins to decrease from the inner boundary of about 6,000K to a minimum of approximately 3,800K (Avrett, 2003) before increasing to upwards of 35,000K at outer boundary with the transition layer of the corona. The chromosphere glows faintly relative to the photosphere and can only be seen easily in a total solar eclipse (a solar eclipse is a type of eclipse that occurs when the Moon passes between the Sun and Earth, and the Moon fully or partially blocks the Sun), where its reddish colour is revealed. However, without special equipment, the chromosphere cannot normally be seen due to the overwhelming brightness of the photosphere.

The Corona

The corona is the third layer which extends into the interplanetary space. It has a density of $10^{15}m^{-3}$ near the Sun, extending out to the earth's orbit (where the density is $10^{7}m^{-3}$) and beyond (kivelson, 1995, Schrijver *et al*, 2000). The solar corona temperature can reach about 1000,000K. This implies that the corona is a very hot layer of the solar atmosphere.

The high temperature of the corona presents one of the most puzzling problems of solar physics. The chromosphere and photosphere are closer to the Sun's core than is the corona, but the corona is several hundred times hotter than the chromosphere and photosphere.

The temperature of the solar corona subsequently decreases as the corona expands into interplanetary space. The corona expands into interplanetary space because the sun is not in static equilibrium. This expanding corona is called *Solar Wind* and was detected by space-born instrument early in the space era (Parks, 1991). The Solar Wind is a flow of ionized solar plasma (stream of charged particles) and a remnant of the solar magnetic field that pervades interplanetary space. These particles can escape Sun's gravity because of their high kinetic energy and high temperature of the corona (Meyer-Vernet, 2007).

III. Gyro-frequency and gyro-period

The gyro-frequency ω of a particle moving under the influence of magnetic field is given as

$$\omega = \frac{|q|B}{m} = 2\pi f \qquad (1)$$

Where ω is in radians/second, q is the charge of either electron or ion (in coulombs, C), m is the mass of either electron or ion (in kilogram, kg), B is the magnetic field (in teslas, T). Gyro-frequency is always defined as a positive number independent of the sign of the charge q.

Gyro-Period is the time it takes the plasma particle to complete one revolution is called the Gyro-period.

Gyro period (cyclotron period, Larmor time) is defined mathematically as:

$$\mathrm{T} = \frac{1}{f} = \frac{2\pi}{|\omega|} = \frac{2\pi m}{|q|B} \qquad (2)$$

This implies that T is inversely proportional to B

Where

T is the gyro-period in seconds (s)

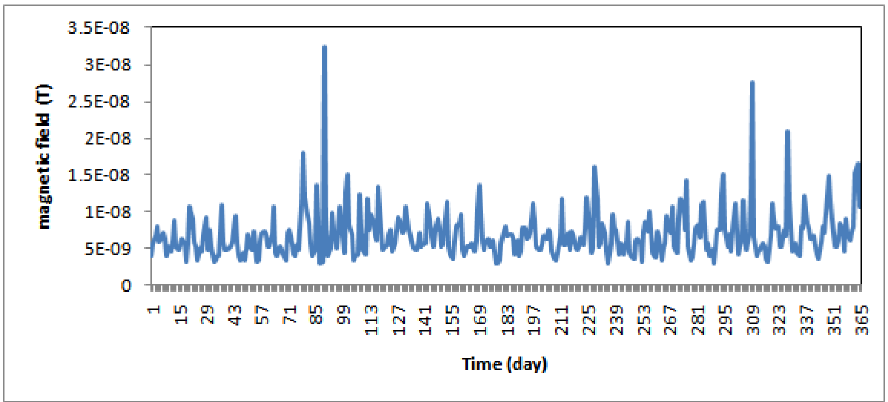
ω is the gyro- frequency.

IV. Observations:

The interplanetary magnetic field data used in this work were obtained from COHOWEB documentation. The particle magnetic field covers the x, y, and z coordinates but only the magnitude was used.

The data covers 365 days of the year 2001. The data contains the days and the magnetic fields for the year 2001. The magnetic field profile for this period is shown in figure 1 below:

Figure 1 Original magnetic field profile for 2001



The massive burst of solar wind and magnetic fields could be responsible for the excessive rise of the signal shown in Fig. 1. According to (Christian 2012), coronal mass ejection (CME) is a massive burst of solar wind and magnetic fields rising above the solar corona or being released into space.

V. Results and analysis:

Gyro-Period and its relationship with magnetic field

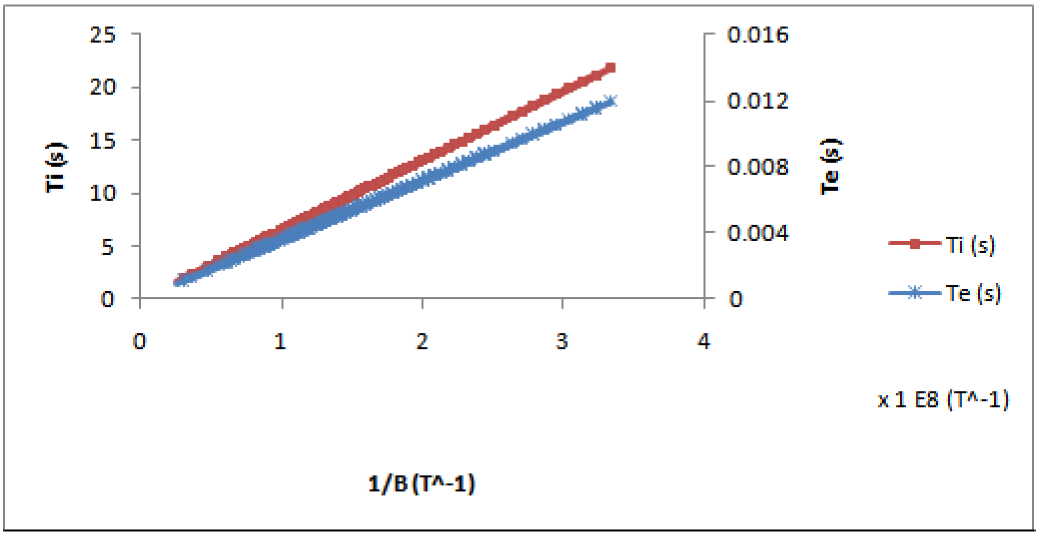


Fig. 2: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for the year 2001.

Figure 2 shows the graph of Gyro-period T (in seconds) versus inverse of Magnetic field $\frac{1}{B}$ (in per Tesla) for the year 2001. This graph shows the relationship between the Gyro-period and Magnetic field. As the magnetic field increases, gyro-period decreases. But gyro-period varies linearly with the inverse of magnetic field.
From the graph in Figure 2, it is shown that the electrons have very small gyro-period compared to the ion. This is because electrons are lighter particles, while the ions are heavier particles. This signifies that in a stream of plasma, the electrons will always move faster than the ions.

Monthly Analysis of Gyro-Period

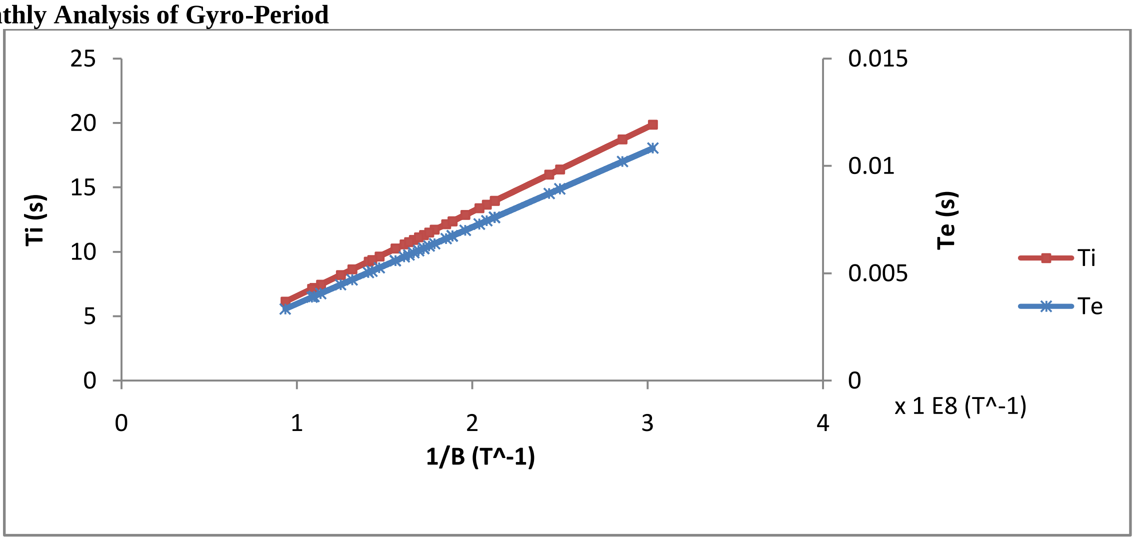


Fig. 3: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for January.

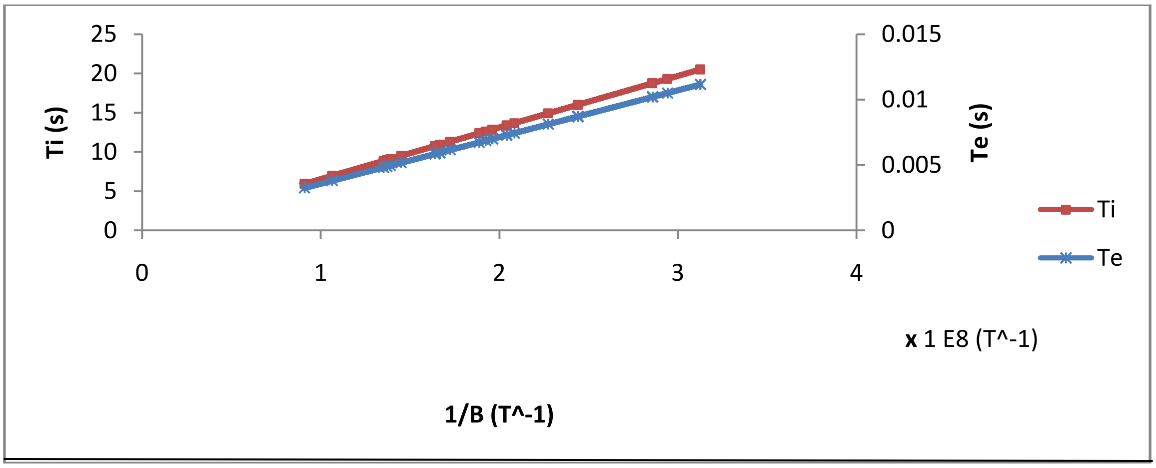


Fig. 4: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for February.

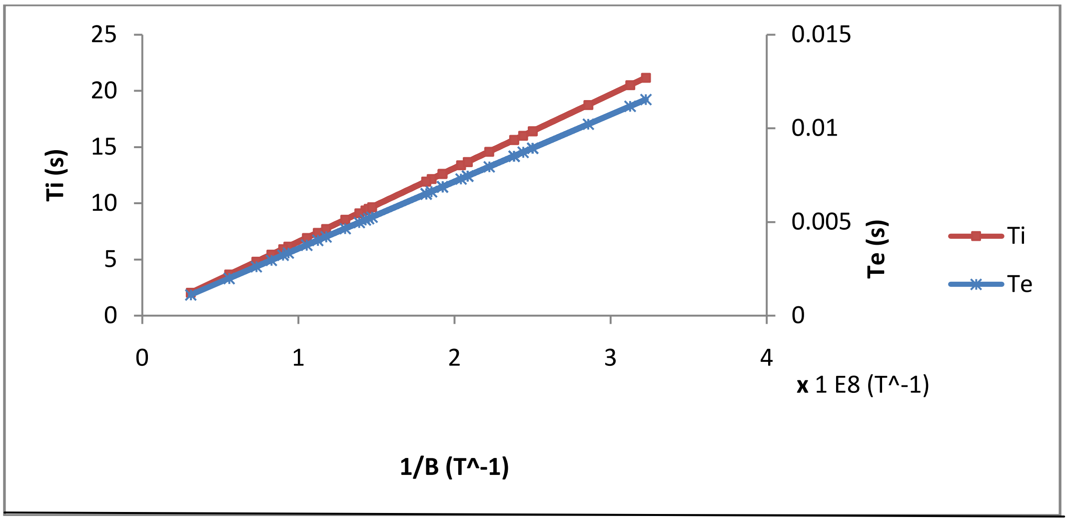


Fig. 5: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for March.

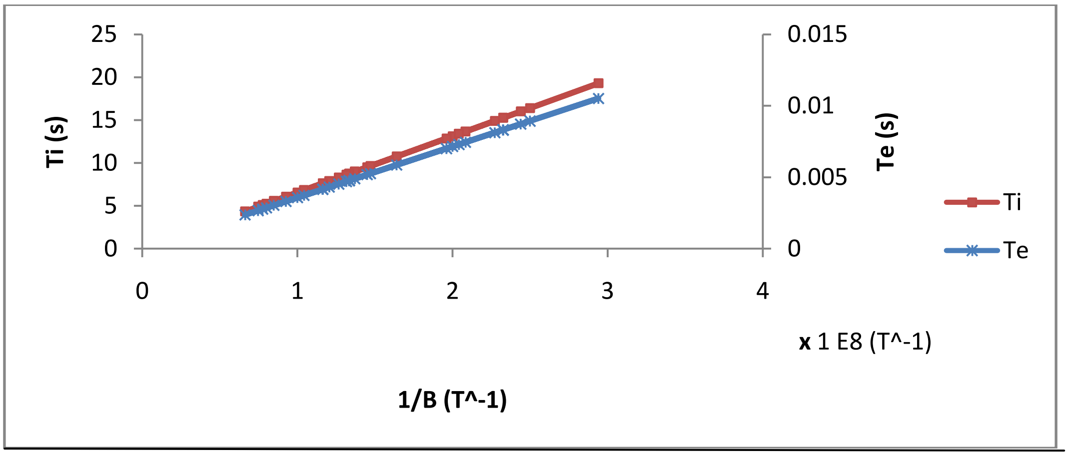


Fig. 6: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for April.

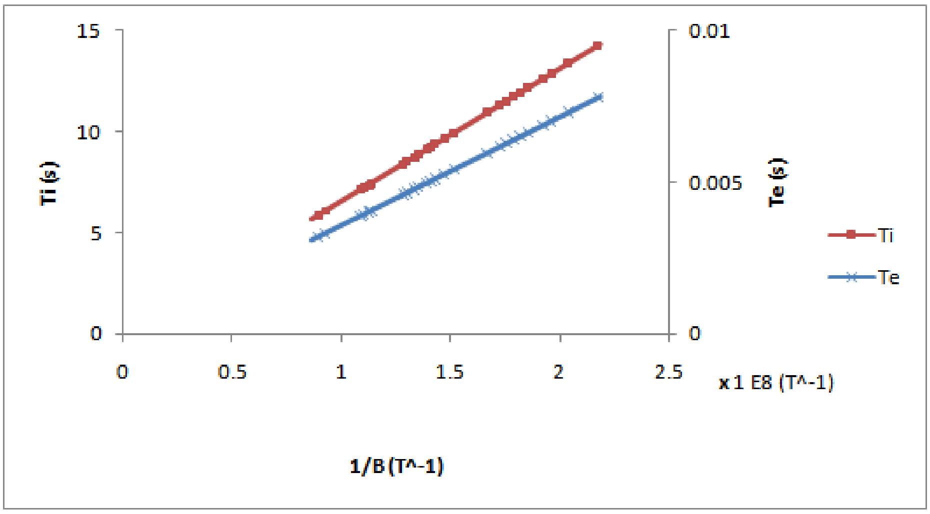


Fig. 7: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for May.

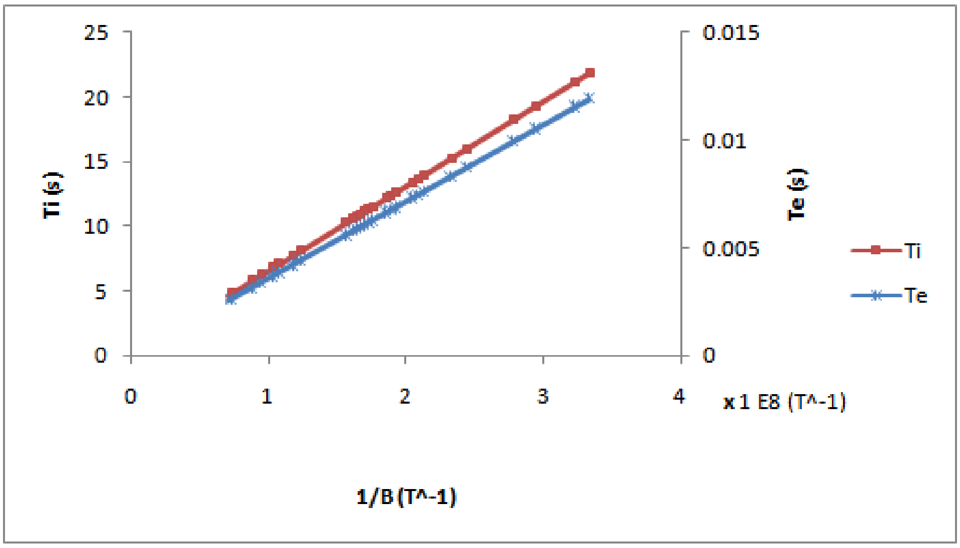


Fig. 8: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for June.

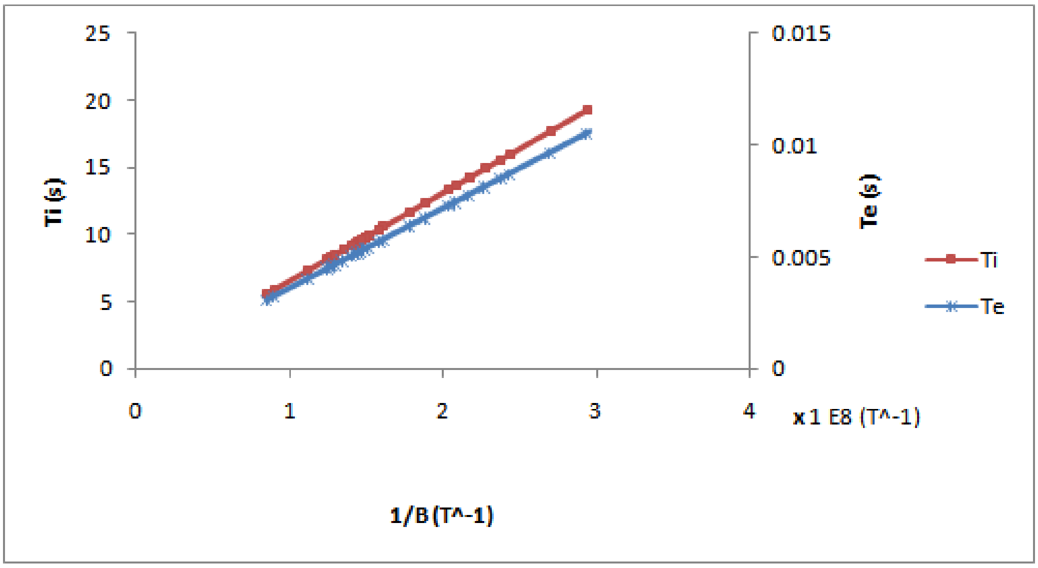


Fig. 9: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for July.

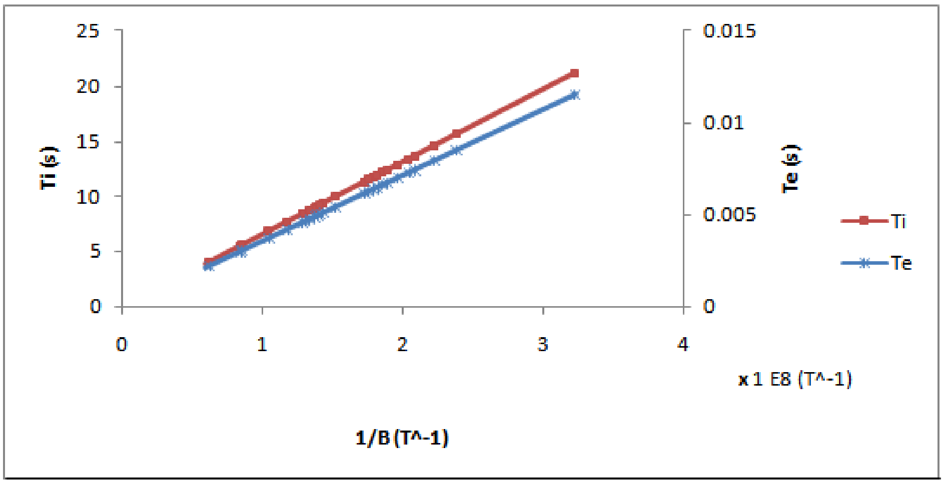


Fig. 10: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for August.

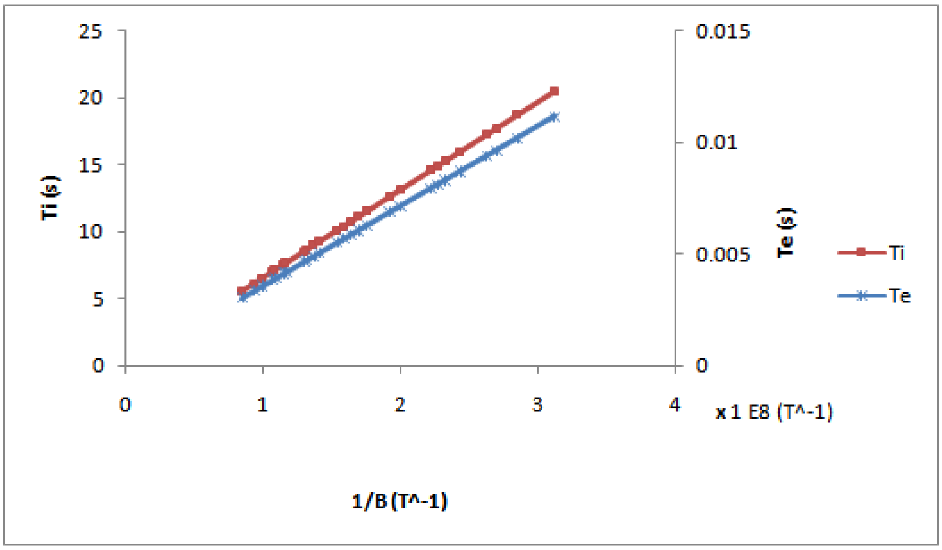


Fig. 11: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for September.

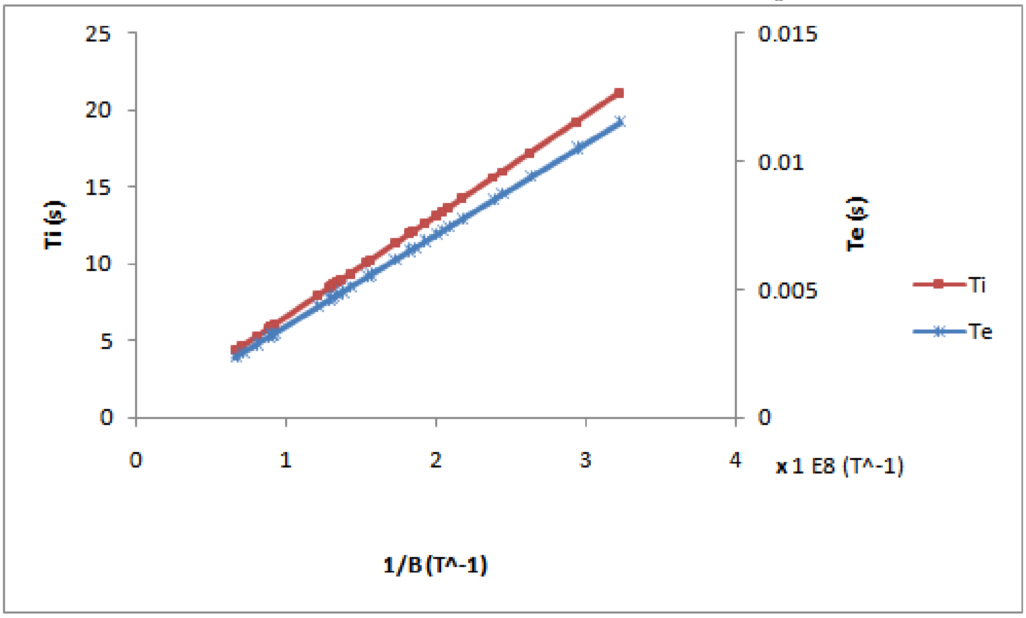


Fig. 12: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for October.

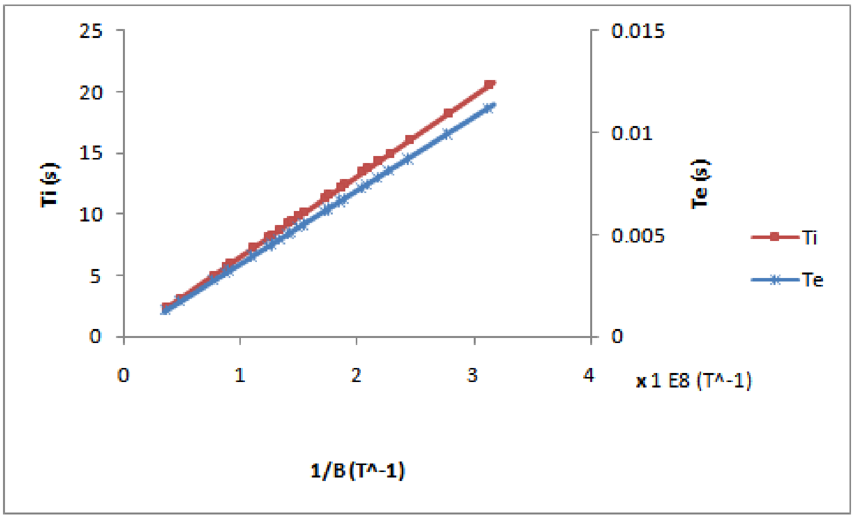


Fig. 13: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for November.

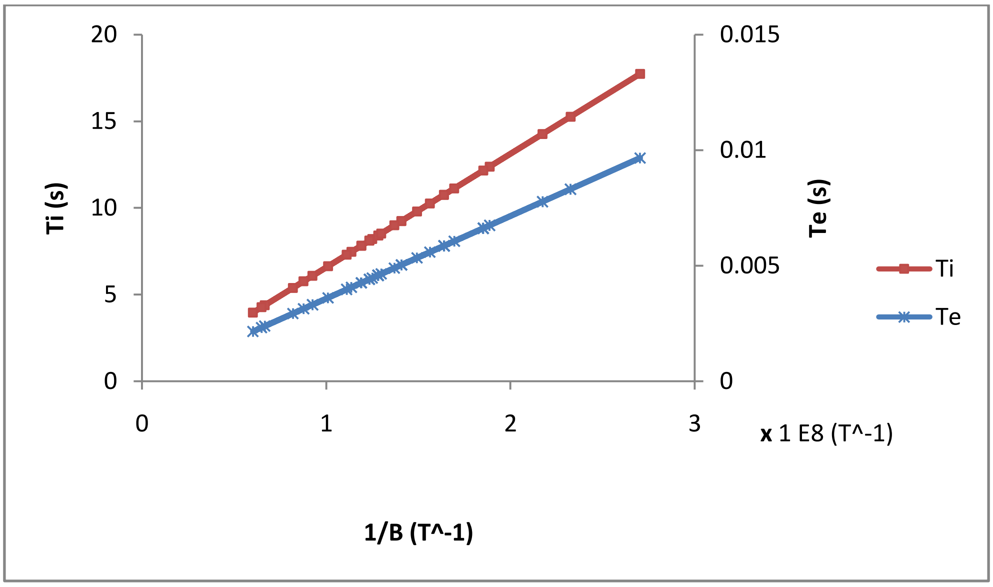


Fig. 14: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for December.

Figures 3-14 show the graph of gyro-period T (s) versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for each month of the year 2001. January, February, March, June, August, September, October, November, as shown in Figures 3, 4, 5, 8, 10, 11, 12 and 13 have their maximum ion gyro-period range between 20-22s, and their maximum electron gyro-period range between 0.01-0.013s. April, as shown in Figure 6, has it maximum ion gyro-period at about 19s, and it maximum electron gyro-period at about 0.01s. May, as shown in Figure 7, has it maximum ion gyro-period at about 15s, and it maximum electron gyro-period at about 0.007s. July, as shown in Figure 9, has it maximum ion gyro-period at about 29s, and it maximum electron gyro-period at about 0.01s. December, as shown in Figure 14, has it maximum ion gyro-period at about 18s, and it maximum electron gyro-period at about 0.01s.

Variations of gyro-periods in each month are as a result of changes in the magnetic field. As earlier stated, changes in solar magnetic field could be influenced by the solar activities. This suggests that within a year, there are some activities going on in the Sun. It also suggests that for various streams of plasma, the particle movement are not the same, sometimes they could be faster or sometimes they could be a bit slow.

Seasonal Analysis of Gyro-Period

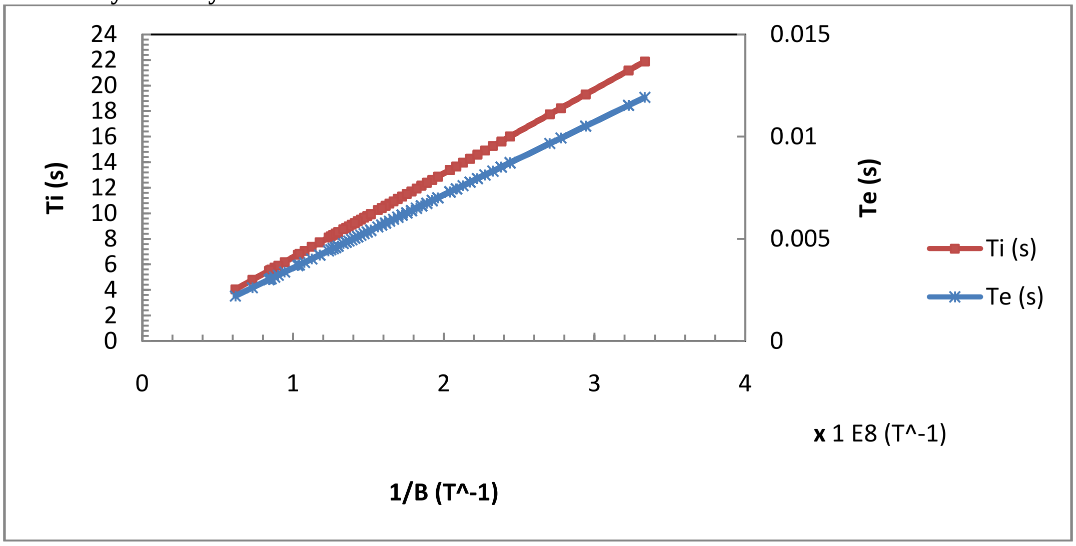


Fig. 15: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}(T^{-1})$ for Summer season (June, July, and August).

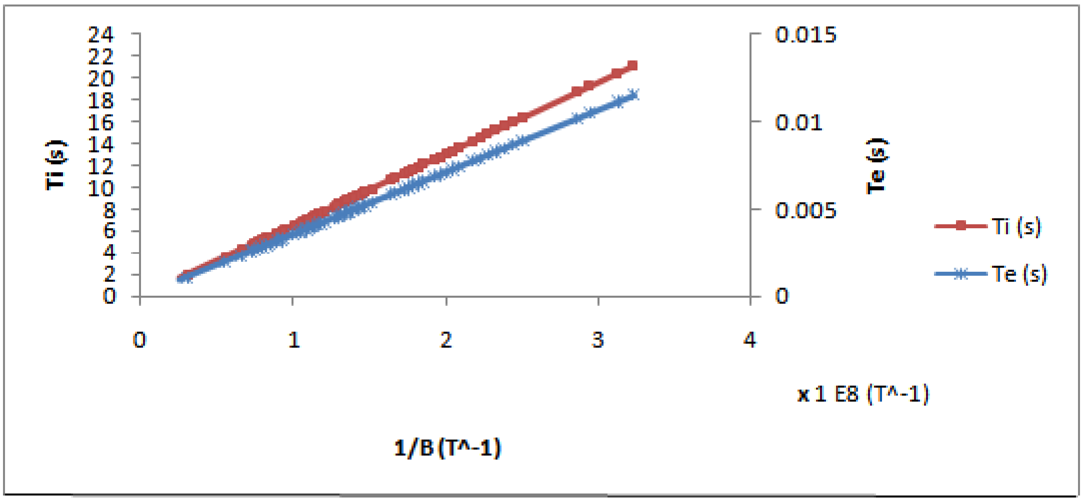


Fig. 16: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for Spring season (March, April, and May).

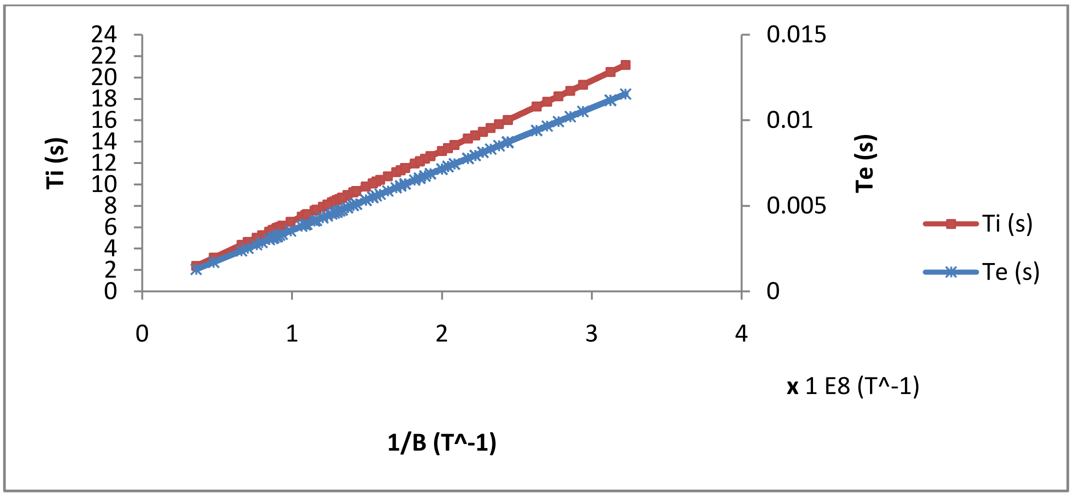


Fig. 17: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}(T^{-1})$ for Autumn season (September, October, and November).

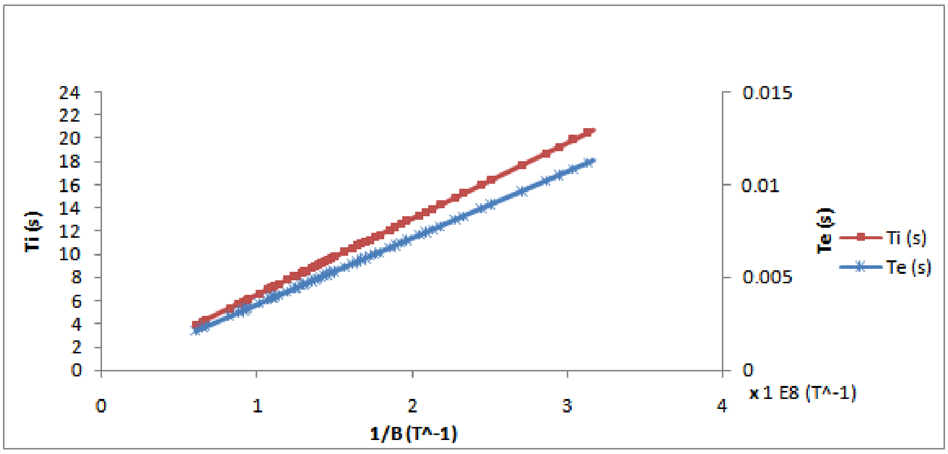


Fig. 4.18: A graph of Gyro-period $T(s)$ versus inverse of Magnetic field $\frac{1}{B}$ (T^{-1}) for Winter season (December, January, and February).

According to Redmond (2008) a year is divided into four Seasons defined by the position of Earth in its orbit around the Sun. The seasons are winter, spring, summer, and autumn and they are characterized by differences in average temperature and in the amount of time that the Sun is in the sky each day.

Figures 15 -18 show the graph of gyro-period T versus inverse of magnetic field $\frac{1}{B}$ for the different four seasons. A close examination of those graphs shows that their maximum ion gyro-period ranges between 22-21s, and their maximum electron gyro-period range between 0.011-0.012. There is no tangible difference between any of the seasons. This suggests that the seasons are not influenced by changes in magnetic field, and thus not influenced by solar activities. So seasonal changes on earth has nothing to do with what is going on in the Sun. It could be concluded that seasonal changes on earth is only based on the rotation/revolution of the earth around the Sun.

VI. Conclusion

From the results and analysis, it was observed that gyro-period depends majorly on the magnetic field strength and the mass of the particle. From the analysis of the result obtained, the electrons which are of lighter particles have very small gyro-period compared to ions which are of heavier particles. Meaning that the electrons move faster in a stream of plasma.

It is also very evident that when there are major catastrophic effects in our atmosphere, the electrons are always the cause. This is true since the bombardment of our atmosphere by these high speed or energy particles can produce ionization. This also can lead to conduction.

These analyses have shown that the Sun's magnetic field is not constant which agrees with the general statement that the *Sun is not in static equilibrium*. And its variation is influenced by solar activities which in turn affects the gyro-period of the plasma particles. These influences of solar activities agrees with the statement by Christian, 2012, that *coronal mass ejection (which is a solar activity) is a massive burst of solar wind and magnetic field.*

The result analysis has also shown that solar activities have no effect on the seasonal changes on earth. This agrees with the statement by Khavrus, and Shelevytsky, 2010, that seasons result from the yearly orbit of the Earth around the Sun and the tilt of the Earth's rotational axis relative to the plane of the orbit.

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