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Grad B Drifts of Heavy Ions Solar Energetic Particles at Solar Corona Region

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Abstract

The objective of this research study the Grad B drifts velocity of the heavy ion of the solar wind (C^{+4}, C^{+5})at corona region with distance (1 to 15) * $6.69*10^8$m for two varied angles (Θ= 90º, 180º). It has been studied, that grad B drifts velocity, in the model of Parker spiral. within single particle dynamics model, in a spherical coordinate system (local coordinate system with an axis aligned with the magnetic field). This work result shown that, azimuthal grad B drift velocity, $V_{\nabla B\varphi}$` takes maximum value at polar zone for ($C^{+4}$, $C^{+5}$) for both velocities of solar wind. Also, there is no azimuthal grad B drifts $V_{\nabla B\varphi}$` at equators zone. And as for colatitude grad B drift velocity, $V_{\nabla B\theta}$` takes high value at most of regions and the highest value at polar zone for fast and slow solar winds. And noting that the slow solar winds have higher values than fast solar wind at the equator region.

Key words: Corona of the Sun, Sun’s Plasma Stream, Grad B drift, heavy ions, Energetic solar Particles.

Introduction

The radiation properties that can be linked to elements and climatic phenomena are related to solar sunspots, these properties exhibit annual oscillations based on solar activity, with a periodicity that repeats every 11 years (small cycle) or 22 years (grand cycle) [1]. The Sun's very hot atmosphere extends continuously into space, giving rise to the solar wind that carries along its magnetic field. This process carves out a cavity in the interstellar medium, expanding well beyond the outer planets, where the solar magnetic field exerts control [2]. In 1951, Biermann inferred from the characteristics of comet ion tails, that the planetary System seems full with ionized particles, always flowing outward from the Sun. Building upon Biermann's idea; Parker (1958) associated the sustained emission of solar particles with the prior finding of the elevated-temperature corona. He finished that; these notions are inseparably connected. Moreover, the steep gradient of gas pressure in the high temperature corona generates an external force opposing gravitation, enabling a stable acceleration of plasma moving further from the Sun. For this phenomenon, Parker introduced the expression "solar wind" [3]. Traces of heavier elements, alongside electrons and protons, are recognized emissions from the solar corona [4]. Elemental abundances in the heliosphere mirror that of the Sun, measured during both solar energetic particle (SEP) events and quiet periods. Abundant elements in SEP events, excluding hydrogen, include helium, carbon, nitrogen, oxygen, neon, magnesium, silicon, and iron [5]. Elements heavier than hydrogen are commonly referred to as heavy ions [5]. Drift effects play a pivotal role in charged particle transmission within the heliosphere, where the unsettled magnetic field mitigates drift effects [6]. Solar energetic particles (SEPs), consisting of high-energy ions and electrons, originate in proximity to the Sun, with their first observation dating back to the early 1940s. These particles expand outward from solar wind. The production of SEPs is typically associated with a sudden increase in solar brightness known as a solar flare, often but not always accompanied by a substantial release of plasma and magnetic fields from the solar corona, termed a coronal mass ejection (CME) [7 .[

In previous studies in 2020, S.Dalla existing 3D simulations of relativistic proton spread from the Sun to 1 AU, which involved 3D effects linked with particle drift and the existence of a HCS (Helispherical Current Sheet) [8]. And A. Hutchinson in 2021 use 3D exam particle simulations, which naturally include the effect of drifts, to simulate the spread of SEPs from a moving shock-like source, and study the effect of an expanding shock-like source spreading through interplanetary space, as against an SEP source within the corona, on the obvious properties [9]. In addition, N.Wijsen in 2021 Investigate how the magnetic gradient and curvature drifts influence the pitch-angle dependent transport of energetic solar particles (SEPs) in the heliosphere of SEPs at 1 AU and at sites closer the Sun [10]. And Lulu Zhao defines one physics-based energetic solar particle model, called Solar-wind with Field-lines and Energetic-particles (SOFIE), this model is designed to simulate the acceleration and transportation procedures of energetic particles of the sun in the interplanetary space and solar atmosphere [11]

Theory and Calculations

The gradient drift, also known as the grad B drift velocity, occurs when there is a magnetic field gradient perpendicular to its direction [12]. In this phenomenon, magnetic field lines remain straight, but their density increases. The variation in the magnitude of the magnetic field |B| leads to a larger Larmor radius at the bottom of the orbit compared to the top, inducing a drift movement [13]

It was found at this research, the azimuthal and colatitude grad B drift velocities $V_{\nabla B\varphi`}, V_{\nabla B\theta`}$ for fast and slow solar wind ions (C^{+4}, C^{+5}) according to equations (2), (3) $V_{\nabla B\varphi`}$ $V_{\nabla B\theta`}$,components depending on the particle energy and the value of this energy for C^{+4},C^{+5} equivalent to 143 Kev [14]. B is solar magnetic field=4.12 n Tesla [15]. r = 1 to 15 R⊙, R⊙ radius of the sun = 6.69*10^{8}m [16], μ is the magnetic momentum, Ω the solar rotation rate = 2.86*$10^{(-6)}$ rad sec $^{(-1)}$ [16]. Dalla et al. formulated an equation to calculate the grad B drift velocity in Solar Energetic Particles (SEPs) within the corona region, considering the conditions outlined in the Parker model [16}

$$V\ \nabla B_{\iota} = 0 \ , \quad (1)$$

$$V\ \nabla B\varphi` = \frac{\mu c}{q}\frac{1}{(r^2+a^2)}\ r\cot\theta\ , \quad (2)$$

$$V\ \nabla B\theta` = -\frac{\mu c}{q}\frac{1}{(r^2+a^2)^{\frac{3}{2}}}\ (r^2+2a^2), \quad (3)$$

Where a is a function, of colatitude θ, and is defined as:

$$a = \frac{us}{\Omega \sin\theta} \quad (4)$$

, us, the velocity of the solar wind

- slow solar wind equals to 400 Km/sec. [17]
- fast solar wind is equals to 800 Km/ sec. [18]

The gradient of magnetic field B drift is contingent on both particle types and speed. In the nonrelativistic approximation, the magnetic momentum μ is defined as:

$$\mu = \frac{m u_{\perp}^{2}}{2B} \quad (5)$$

, m, is the mass of particle

Where $u_{\perp}$, is the perpendicular velocity of particle to the magnetic field and B=|B|.

Result and Discussion

In this research the result and calculation made for the heavy ions energetic solar particles at solar corona region at distance ranging from (1 to 15) R⊙ [19]. The result was obtained by equations presentation by matlab 2013, these computations made in (SI) system unit using spherical coordinates (r, Θ, ϕ) to

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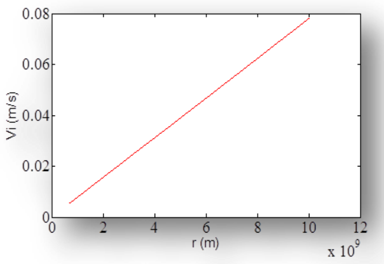
examination and calculate the values and result for the gradient of magnetic field B drift velocity at this region. The results of the grad B drift velocity of ion were compared with the results of Dalla [16] and were approach to them.

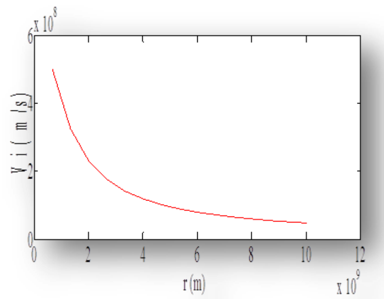
azimuthal grad B drift velocity

It was found that the azimuthal gradient of magnetic field B drift velocity $V_{\nabla B\varphi}$ for two types of speed of solar wind ions (C^{+4},C^{+5}) at two different values of Ө as follows: - Ө= 90°, 180° .

For C^{+4} , C^{+5} at equator region (Ө= 90°) for fast and slow solar wind the grad B drifts velocity at this region is almost nonexistent as show in figure (1, 2). For (C^{+4} ,C^{+5})for slow and fast solar wind at polar region (Ө=180°) the grad B drifts

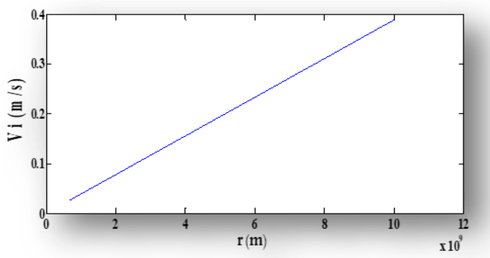
velocity has high values in this region equal to 10^8m $sec^{(-1)}$,and the slow solar wind relatively has higher values as show in figure (1, 2)

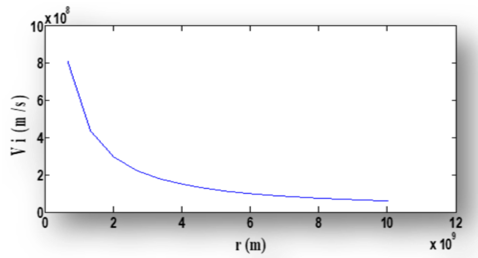




(a) (b)

Ө=90° Ө=180°





(c) (d)

Ө=90° Ө=180°

Fig.1 $V_{\nabla B\varphi}$ for $C^{+5}$for fast (a, b) and slow (c, d) solar wind for two different values of angle Ө, figures (b, d) here be taken the absolute values.

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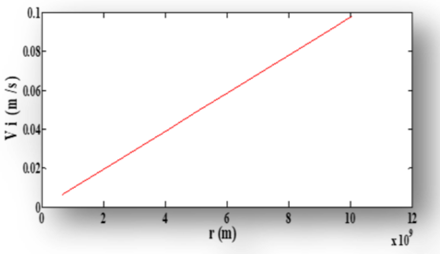
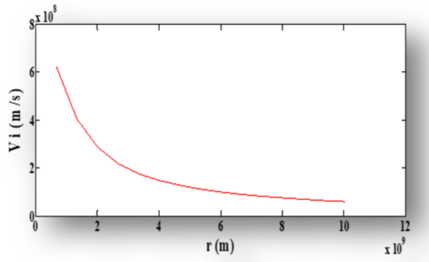
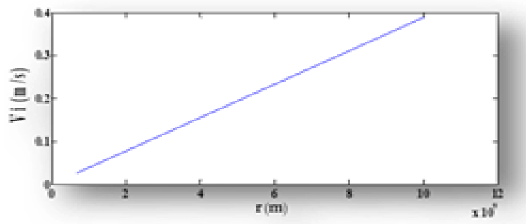


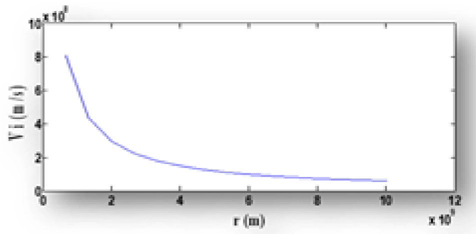
(a)
ϴ=90°



(b)
ϴ=180°



(c)
ϴ=90



(d)
ϴ=180°

Fig.2 $V_{\nabla B\varphi}$ for $C^{+4}$for fast (a, b) and slow (c, d) solar wind for two different values of angle ϴ, figures (b, d) here be taken the absolute values.

colatitude grad B drift velocity

The colatitude grad B drifts velocity for C^{+4} $C^{+5}$for fast and slow solar wind at equator and polar regions has high values and the best values at the polar region equal to 10^6 m.sec^{-1} for C^{+4} for fast solar wind as show in figure (3, 4)

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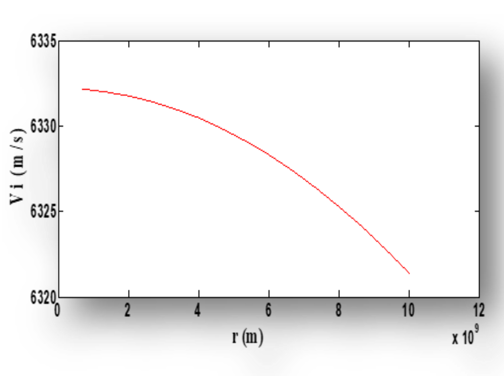
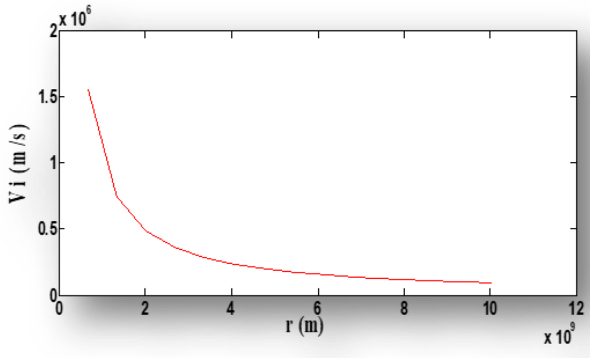


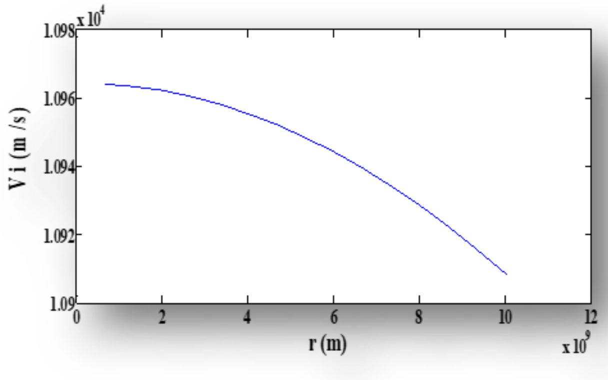
(a)

Θ=90º



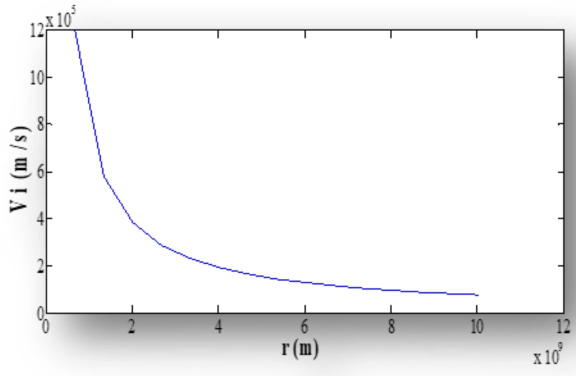
(b)

Θ=180º



(c)

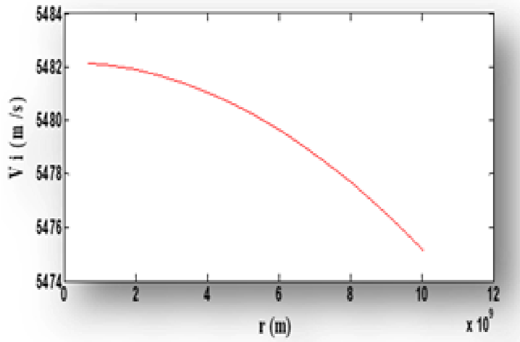
Θ=90º



(d)

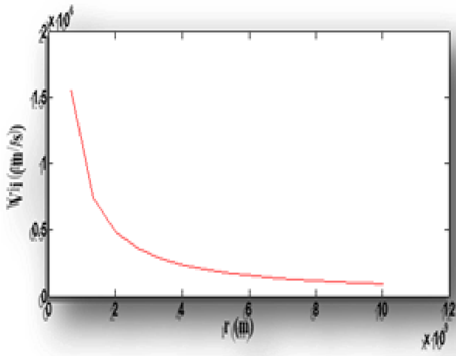
Θ=180º

Fig. 3 $V_{\nabla B\theta}$ for C^{+5} for fast (a, b) and slow (c, d) solar wind for two different values of angle Θ, here it was taken the absolute values



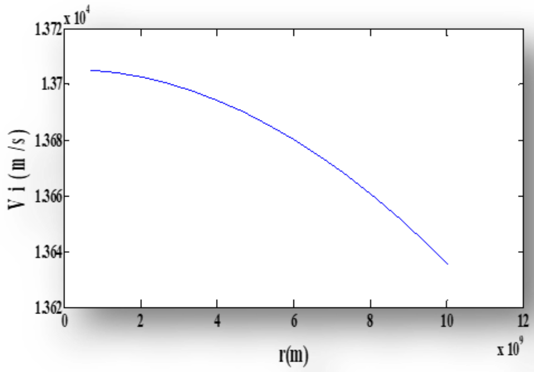
(a)

Θ=90°



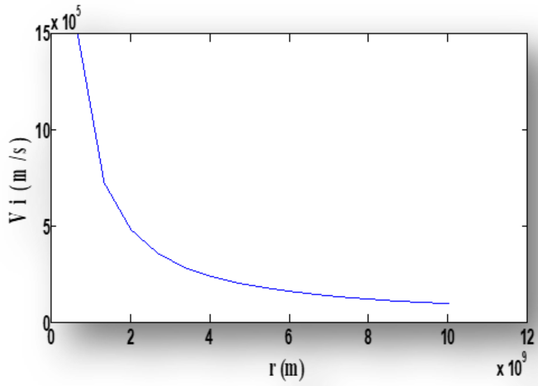
(b)

Θ=180°



(c)

Θ=90°



(d)

Θ=180°

Fig. 4 $V_{\nabla B\theta}$` for C^{+4} for fast (a, b) and slow (c, d) solar wind for two different values of angle Θ, here it was taken the absolute values

Conclusion

The grad B drifts velocity $V_{\nabla B\varphi}$`, $V_{\nabla B\theta}$` parts where the $V_{\nabla B\varphi}$`has maximum values at polar region for $C^{+4}, C^{+5}$ for slow and fast solar wind and the equator region has no grad B drifts for both ions $C^{+4}, C^{+5}$ and slow solar wind has higher value than fast solar wind. The $V_{\nabla B\theta}$` component has high values at all regions for both ions for two types velocity of the solar wind and the maximum values at the polar region.

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مستخلص البحث:
يهدف هذا البحث الى دراسة سرعة انجراف انحدار المجال المغناطيسي B للايون الثقيل للرياح الشمسية(C^{+4}, C^{+5}) في منطقة الهالة الشمسية لمسافة $6.69*10^{8}$m * (1 to 15) لقيمتين اثنتين من الزوايا (ϴ= 90°, 180°). لقد تم دراسة سرعة انجراف انحدار المجال المغناطيسي في عينة باركر الحلزوني ضمن نموذج حركة الجسيم الواحد في نظام الاحداثيات الكروية (نظام الاحداثيات المحلية ضمن المحور الموازي للمجال المغناطيسي)، ونتيجة هذا العمل أظهرت ان سرعة انجراف انحدار B السمتية $V_{\nabla B\varphi}$ لديها اعلى قيمة في المنطقة القطبية لايون (C^{+4}, C^{+5}) لكيلا الرياح الشمسية السريعة والبطيئة. بالإضافة الى عدم وجود انجراف الانحدار السمتي للمجال المغناطيسي في المنطقة الاستوائية، وبالنسبة لسرعة انجراف الانحدار العرضي للمجال المغناطيسي $V_{\nabla B\theta}$ ، فقيمته عالية في اغلب المناطق واعلى قيمة في المنطقة القطبية لكيلا الرياح الشمسية السريعة والبطيئة، مع ملاحظة ان الرياح الشمسية البطيئة قيمها اعلى من الرياح الشمسية السريعة في المنطقة الاستوائية.
الكلمات المفتاحية: التاج الشمسي، الرياح الشمسية، انجراف انحدار المجال المغناطيسي، الايونات الثقيلة،الجسيمات الطاقية الشمسية .