Effect of temperature anisotropy on Alfvén waves in multi-component magnetospheric plasma

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Abstract. The main objective of the present investigation is to examine the effect of temperature anisotropy on Alfvén waves in multi-component plasma by using the method of kinetic approach and using different plasma parameters in auroral acceleration region. In this paper, we are considering the multi-component (Ions and electrons) plasma for the calculations of dispersion relation, growth/damping rate and growth length on Alfvén waves. Dispersion relation, growth/ damping rate and growth length of Alfvén waves are measured in multi-component plasma consisting of mixture of Hydrogen (H$^+$), Helium (He$^+$) and Oxygen (O$^+$) ions. An Alfvén waves is an important electromagnetic wave that transports electromagnetic energy in many space and astrophysical regions. These waves parallel propagate along the magnetic field with parallel wave vector in the x-z plane. Curves show that the damping rate increases of waves with increases temperature anisotropy.

1. Introduction
An Alfvén waves is low frequency electromagnetic waves with wave frequency less than ion or electron cyclotron resonance frequency in magnetospheric plasma. In the Alfvén wave the background magnetic field tension provides the restoring force, whereas the ion mass provides the inertia. The existence of such waves was theoretically predicted by [1]. This theoretical prediction was of great importance because it opened new possibilities to transport energy in a medium. The experimental confirmation of this extremely fruitful idea appeared several years later, when experiments in the Alfvén laboratory in Stockholm proved the existence of these waves in magnetosphere plasma. An Alfvén waves play an important role in energy transport in particle acceleration, and heating in the magnetosphere [2]. Alfvén waves have been invoked as the most promising wave mechanism to explain the heating of Sun’s outer atmosphere, or corona, to millions of degrees and the acceleration of the solar wind to hundreds of kilometres per second [3]. Spacecraft measurements, measurement from the FAST satellite [4] and the POLAR spacecraft [5] have been speculated the existence of small-scale Alfvén waves that carry a large net pointing flux along magnetic field lines towards the earth. The phenomena associated with the Alfvén waves in auroral acceleration region can also be examined by in Situ measurements [6]. Plasma kinetic theory also provides a method of investigation to find the influence of collision among the plasma particle and the calculation of the transport properties of fully ionized plasma. The most fundamental kinetic description of a collision –less plasma system is to employ the Vlasov equation to obtain particle distribution functions for all particle species and compute the electric field and magnetic fields from the particle density and plasma current by the Maxwell’s equation.
1. Dispersion relation

We consider plasmas with external magnetic field \( B_0 \), since the Alfvén waves propagate parallel to the magnetic field in \( z \)-direction with parallel wave vector in the \( x-z \) plane. Here, linear dispersion relation of Alfvén waves in multi-component plasma using auroral acceleration region are evaluated.

\[
\omega^2 = k^2_H v_A^2 k^2_\perp \left[ 1 + (A_{H^+} + A_{He^+} + A_{O^+}) \right] \times \left( \frac{v^2_{T_i H^+}}{\Omega^2_{H^+}} + \frac{v^2_{T_i He^+}}{\Omega^2_{He^+}} + \frac{v^2_{T_i O^+}}{\Omega^2_{O^+}} \right)
\]  

(1)

3. Growth/damping rate

Assuming \( \omega \to \omega + i\gamma \), with \( \gamma < \omega \) we obtain an expression for the collision less damping rate of the Alfvén wave from [7-8] and further we extend the effect of temperature anisotropy on Alfvén waves in multi-component plasma are evaluated.

\[
\gamma = k_H v_A^2 k^2_\perp \frac{1}{v^3_{THe}} \left\{ \pi \cdot \frac{8}{\sqrt{\pi}} (A_{H^+} + A_{He^+} + A_{O^+}) \times \left( \frac{v^2_{T_i H^+}}{\Omega^2_{H^+}} + \frac{v^2_{T_i He^+}}{\Omega^2_{He^+}} + \frac{v^2_{T_i O^+}}{\Omega^2_{O^+}} \right) \right\}^{\frac{1}{2}}
\]  

(2)

4. Growth length

The growth length \( \gamma_L \) of the Alfvén waves (AW’s) is derived from [8-9] as

\[
\gamma_L = \frac{8}{\sqrt{\pi}} \times \frac{v^3_{THe}}{K_H K_\perp v_A} \left\{ 1 + (A_{H^+} + A_{He^+} + A_{O^+}) \times \left( \frac{v^2_{T_i H^+}}{\Omega^2_{H^+}} + \frac{v^2_{T_i He^+}}{\Omega^2_{He^+}} + \frac{v^2_{T_i O^+}}{\Omega^2_{O^+}} \right) \right\}^{\frac{1}{2}}
\]  

(3)

where,

\[
A_{H^+} = \frac{T_{eH^+}}{T_{H^+}}, A_{He^+} = \frac{T_{eHe^+}}{T_{He^+}}, A_{O^+} = \frac{T_{eO^+}}{T_{O^+}}
\]

5. Results and discussions

In the present analysis, the expression for numerical evaluation of the linearly dispersion relation, growth/damping rate and growth length with electron and (hydrogen, helium, oxygen) ion temperature ratio for homogeneous plasma, the following plasma parameter are used which are relevant for auroral acceleration region [9-10].

\[
B_0 = 4300 \times 10^9 T, K_H = 10^{-10}, K_\perp = 10^{-6}, v_{A,\text{multi}} = 4002 \times 10^4, \Omega_{He^+} = 103 \text{ sec}^{-1},
\]

\[
\Omega_{He^+} = 103 \text{ sec}^{-1}, \Omega_{H^+} = 412 \text{ sec}^{-1}, \Omega_{O^+} = 26 \text{ sec}^{-1}, v_{THe} = 1.876 \times 10^4 \text{ cms}^{-1},
\]

\[
v_{T,\perp} = 4.378 \times 10^4 \text{ cms}^{-1}.
\]

Figure 1 shows the variation of wave frequency \( \omega \) (s\(^{-1}\)) with \( K_H \) (cm\(^{-1}\)) for different values of hydrogen, helium, oxygen temperature ratio \( (A_{H^+}, A_{He^+}, A_{O^+}) \). Here, we notice that the wave frequency increases with \( K_H \) and increases with the increases of temperature anisotropy. Figure 2 shows the variation of growth/damping rate \( \gamma \) versus the parallel wave vector \( K_\parallel \) for different values of hydrogen, helium, oxygen temperature ratio \( (A_{H^+}, A_{He^+}, A_{O^+}) \). It is seen that the damping rate increases with the parallel wave vector. Thus, these curves show that the damping rate increases of waves with increases temperature anisotropy.
In this paper, the Alfvén waves have been studied in auroral acceleration region using plasma kinetic theory. The wave dispersion relation, growth/damping rate and growth length are evaluated for Alfvén waves in multi-component magnetospheric plasma. It is observed that the effect of temperature anisotropy on Alfvén wave. The wave frequency increases with $K_{II}$ and increases with the increases of the temperature anisotropy. It is found that the higher wave frequency at lower value of $K_{II}$ (cm$^{-1}$). The damping rate increases with $K_{II}$ and increases with the increases of the temperature anisotropy. The growth length of wave is exponential decreases with increases the parallel wave vector but decreases with the increases of temperature anisotropy. Here, it is notice that the growth length becomes greater than $1R_E$ on the lower value of $K_{II}$ (cm$^{-1}$).

6. Conclusions
In this paper, the Alfvén waves have been studied in auroral acceleration region using plasma kinetic theory. The wave dispersion relation, growth/damping rate and growth length are evaluated for Alfvén waves in multi-component magnetospheric plasma. It is observed that the effect of temperature anisotropy on Alfvén wave. The wave frequency increases with $K_{II}$ and increases with the increases of the temperature anisotropy. It is found that the higher wave frequency at lower value of $K_{II}$. Finally, the wave frequency is much lower than the ion cyclotron frequency on the value of $K_{II}$ (cm$^{-1}$). The damping rate increases with $K_{II}$ and increases with the increases of the temperature anisotropy. The growth length of wave is exponential decreases with increases $K_{II}$ and decreases with the increases of temperature anisotropy. It is found that the growth length is a greater than $1R_E$ on the lower value of $K_{II}$. The findings may be applicable to explain the Alfvén waves in space, astrophysical plasma and magnetospheric plasma.

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