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# GRADIENT EFFECT ON KELVIN HELMHOLTZ INSTABILITY IN THE PRESENCE OF INHOMOGENEOUS D. C. ELECTRIC FIELD

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**Abstract**—Kelvin-Helmoholtz instability by parallel flow velocity shear in presence of inhomogeneous d.c. electric field and perpendicular density temperature magnetic field gradient has been studied by using method of characteristic solution and kinetic approach. Effect of in homogeneity of d.c. electric field and gradient have been discussed in result. The growth rates have been calculated for different effects and showing in stabilizing and destabilizing of instability.

## 1. INTRODUCTION

Kelvin-Helmholtz instability resulting from velocity shear in fluid dynamics has an analogous counterpart in planetary magnetopause and could account, at least in past, for the entry of solar wind plasma in to the closed field lines of the magnetosphere [1]. Results of research to date have provided a strong observational and theoretical case for existence of a magnetopause K-H instability [2–12]. Recently microstructure of magnetopause was done by analyzing AMPTE/CCE and ISEE2 space craft data [13]. The shape, field and structure of the magnetopause was inferred analytically and by simulation technique [14, 15]. Simulation of K-H instability for magnetospheric calculations are numerous and extend from MHD calculations [16–18], to hybrid calculations [19–21] and full particle calculations [22, 32, 33]. Kinetic simulation of the K-H instability including three-dimensional simulation was studied by [23, 24] and applied to dayside magnetopause. In a collisionless magneto-plasma Kelvin-Helmholtz instability were investigated analytically by Kineti approach [25–28]. Investigated the electrostatic ion-cyclotron by

Kinetic approach for sheared velocity flow perpendicular to uniform magnetic field. It was found that for small velocity shear parameters the instability exists at long wave-length as well as at short wave length also.

In recently electrostatic Kelvin-Helmoholtz instability by parallel flow velocity shear in presence of inhomogeneous d.c. electric field and only density gradient has been studied by Pandey et al. [29] and velocity shear ion-cylotron instability with perpendicular a.c. electric filed has been also studied by Pandet et al. [36].

In this paper a microscopic study of K-H instability was reinvestigated by incorporating the details of particle trajectories in the presence of non-uniform electric field having density, temperature, and magnetic field gradients by method of characteristics solution. In this paper detail of particle trajectories, dispersion relation and calculation of growth rate for bi-Maxwellian plasma with velocity shear have been obtained.

## 2. DISPERSION RELATION

The particle trajectories under the given geometrical conditions and in the presence of inhomogeneous external DC electric field and homogeneous magnetic field has been given by Pandey et al. [29] as,

$$
\begin{aligned}
x(\iota) &= x_0 + \frac{v_\perp}{\Omega_s}\left(1 + \frac{\overline{E'}(x)}{4\Omega_s^2}\right)[\sin(\theta - \Omega_s t) - \sin\theta] \qquad (1)\\
y(\iota) &= y_0 + \Delta + \frac{v_\perp}{\Omega_s}\left(1 + \frac{3}{4}\frac{\overline{E'}(x)}{4\Omega_s^2}\right)[\sin(\theta - \Omega_s t) - \cos\theta]\\
z(\iota) &= z_0 + v_{||}\iota
\end{aligned}
$$

where,

$$
\begin{aligned}
\Delta &= \frac{\overline{E'}(x)\iota}{\Omega_s^2}\left[1 + \frac{E''(x)}{E(x)} \cdot \frac{1}{4}\left(\frac{v_\perp}{\Omega_s}\right)^2 \cdots\right]\\
\overline{E'}(x) &= \frac{e_s E(x)}{m_s}\\
E(x) &= E_{0x}\left(1 - \frac{x^2}{a^2}\right), \quad P = \frac{2x}{a}\\
\Omega_s &= \frac{e_s B_0}{m_s}
\end{aligned}
$$

After doing some lengthy algeraic simplifications following techniques out lined in [29–31, 34, 35] the time integration gives the perturbed distribution function as

$$\begin{aligned} f_{s1}(r,v,t) &= \frac{ie_s}{m_s\omega}\sum_{m,n,p,g} J_n(\lambda_1) J_m(\lambda_1) J_p(\lambda_2) J_g(\lambda_2) \\ &\quad e^{i(m-n)(\pi/2+\theta)} e^{i(g-p)(\pi/2+\theta)} \\ &\quad \times \left[E_{1x}U^* + V^*E_{1y} + W^*E_{1z}\right] \\ &\quad \times \frac{1}{k_{||}v_{||} + n\Omega_s + p\Omega_s + k_\perp\Delta' - \omega} \end{aligned} \tag{2}$$

where

$$\begin{aligned} U^* &= Cv_\perp\frac{n}{\lambda_1} - Cv_\perp\frac{n}{\lambda_1}\frac{\overline{E'}(x)}{4\Omega_s} + k_\perp v_\perp\xi''\frac{n}{\lambda_1} + k_\perp v_\perp\xi''\frac{\overline{E'}(x)}{4\Omega_s^2}\frac{n}{\lambda_1} \\ V^* &= iCv_\perp\frac{J_n'}{J_n} + \frac{3}{4}Cv_\perp\frac{\overline{E'}(x)n}{\Omega_s^2\lambda_1} - \Delta'C \\ W* &= \omega\frac{\partial fs_0}{\partial v_{||}} + Dk_\perp v_\perp\frac{n}{\lambda_1} + \frac{3Dk_\perp v_\perp}{4}\frac{\overline{E'}(x)}{\Omega_s^2}\frac{n}{\lambda_1} \\ C &= \left(\omega - k_{||}v_{||}\right)\left(\frac{-2fs_o}{\alpha_s^2}\right) + k_{||}\frac{\partial fs_o}{\partial v_{||}} \\ D &= v_{||}\left(\frac{2fs_o}{\alpha_{\perp s}^2}\right) - \frac{\partial fs_o}{\partial v_{||}} \\ \lambda_1 &= \frac{k_\perp v_\perp}{\Omega_s} \\ \lambda_2 &= \frac{3}{4}\frac{k_\perp v_\perp\overline{E'}(x)}{\omega_s^3} \\ \Delta' &= \frac{\delta\Delta}{\delta t} \end{aligned}$$

The unperturbed bi-Maxwellian distribution function is written as

$$\begin{aligned} f_{s0} &= f_{m0} + v_y\xi'' \\ \xi'' &= \frac{1}{\Omega_s}\left[\varepsilon_n + \left(\frac{\left(v_{||} - v_{0z}(x)\right)^2}{\alpha_{||s}^2} - \frac{3}{2}\right)\varepsilon_T \right. \\ &\quad \left. + \frac{2\left(v_{||} - v_{0z}(x)\right)}{\alpha_{||s}^2}\frac{\delta v_{0z}(x)}{\delta x}\right] f_{mo} \end{aligned} \tag{3}$$

$$f_{mo} = \frac{n_0(x)}{(\pi)^{1/2}\alpha_{\perp s}^2 \alpha_{||s}} \exp\left[-\frac{\left(v_{0x}^2 - v_{0y}^2\right)}{\alpha_{\perp s}^2} - \frac{\left(v_{||} - v_{0z}(x)\right)^2}{\alpha_{||}^2}\right]$$

where $\xi''$ is being constant of motion

$$\alpha_{\perp s}, \alpha_{||s} = \left(\frac{2k_B T_{\perp,||s}}{m_s}\right)^{1/2}$$

Now simplifying $m = n$, $g = p$ and using the definition of current density, conductivity and dielectric tensor, we get the dielectric tensor

$$\|\varepsilon\,(k_1\omega)\| = 1 - \frac{4\pi e_s^2}{m_s\omega^2} \int \frac{d^3v \sum J_p\,(\lambda_2)\, J_g\,(\lambda_3)\, \|S_{ij}\|}{k_{||}v_{||} + n\Omega_s - p\Omega_s + k_\perp \Delta' - \omega} \tag{4}$$

where

$$\|S_{ij}\| = \begin{vmatrix} J_n^2 U^* \frac{n}{\lambda_1} v_\perp & J_n^2 V^* \frac{n}{\lambda_1} v_\perp & J_n^2 W^* \frac{n}{\lambda_1} v_\perp \\ -iJ_n J_n' U^* V_\perp & -iJ_n J_n' V^* v_\perp & -iJ_n J_n' W^* v_\perp \\ J_n^2 U^* V_{||} & J_n^2 V^* v_{||} & J_n^2 W^* v_{||} \end{vmatrix}$$

Now we consider electrostatic K-H instability

$$\left\|\varepsilon_{||}\right\| = N^2 \tag{5}$$

where $N =$ refractive index

The required electrostatic dispersion relation can be obtained by using the approximation of [25] and from Equations (1 to 4).

$$\begin{aligned} D(k,\omega) \;=\; & 1 + \frac{2\omega_{ps}^2}{k_\perp^2 \alpha_{\perp s}^2} \Gamma_0\,(\mu_s) \sum J_P^2\,(\lambda_2) \\ & \left[1 - \frac{E'(x)}{4\Omega_s^2}\right] \frac{k_\perp}{k_{||}} \left[\left[\left(\frac{\overline{\omega}}{k_{||}\alpha_{||s}} - \frac{1}{2}\varepsilon_n \rho_s \frac{\alpha_{\perp s}}{\alpha_{||s}}\right) Z(\xi)\right.\right. \\ & \left. -A_s \frac{\alpha_{\perp s}^2}{\alpha_{||s}^2}(1 + \xi Z(\xi)) + A_T \frac{k_{||}}{k_\perp}(1 + \xi Z(\xi))\right] \\ & \left. -\frac{1}{2}\varepsilon_n \rho_s \frac{\alpha_{\perp s}}{\alpha_{||s}} \left(\xi(1 + \xi Z(\xi)) - \frac{3}{2} Z(\xi)\right)\right] \end{aligned} \tag{6}$$

where $Z(\xi)$ is plasma dispersion function

$$\xi = \frac{\overline{\omega} - (n+g)\Omega_s - k_\perp \Delta'}{k_{||}\alpha_{||}}, \quad \varepsilon_n = \frac{\partial \ln n(x)}{\partial x}$$

$$A_s = \frac{1}{\Omega_s}\frac{\delta v_{oz}(x)}{\delta x}, \quad \varepsilon_T = \frac{\partial \ln T(x)}{\partial x}$$
$$A_T = \frac{\alpha_{\perp s}^2}{\alpha_{||s}^2} - 1$$

$$\overline{\omega} = \omega - k_{||} v_{oz}(x)$$
$$\mu_s = \frac{k_\perp^2 \rho_i^2}{2}$$
$$\lambda_{Ds}^2 = \frac{\alpha_{\perp s}^2}{2\omega_{ps}^2}$$
$$\omega_{ps}^2 = \text{Plasma frequency}$$

Above dispersion relation reduces to that of [25] if inhomogeneous DC electric field is removed and $\alpha_{\perp s} = \alpha_{||s}$ an following the assumption of Huba [25] for $p = 1$, $g = 0$ and $s = i, e$. In order to get dispersion relation for electrons and ions, approximations for electrons are assumed as $k_\perp \rho_e \ll 1$ and for ions no such assumptions in done thus above equation becomes.

$$\begin{aligned} D(k,\omega) = 1 &+ \frac{1}{k_\perp^2 \lambda_{\text{De}}^2}\eta_e \frac{T_{\perp e}}{T_{||e}} + \frac{1}{k_\perp^2 \lambda_{\text{Di}}^2}\eta i \left[\frac{T_{\perp i}}{T_{||i}}\Gamma_0(\mu_i)\frac{k_\perp}{k_{||}}\left[\left(\frac{\overline{\omega}}{k\alpha_{||i}} \times \frac{T_{\perp i}}{T_{||i}}\right.\right.\right. \\ &\left. -\frac{1}{2}\varepsilon_n \rho_s \frac{\alpha_{\perp i}}{\alpha_{||i}} + \frac{n\Omega_i + k_\perp \Delta'}{k_{||}\alpha_{||i}}\left(1 - \frac{T_{\perp i}}{T_{||i}}\right)\right) Z(\varepsilon_i) - A_i \frac{T_{\perp i}}{T_{||i}} \\ &\left. (1 + \xi Z(\varepsilon_i)) - \frac{1}{2}\varepsilon_n \rho_s \frac{\alpha_{\perp s}}{\alpha_{||s}}\left(\xi\left(1 + \xi Z(\xi)\right) - \frac{3}{2}Z(\xi)\right)\right] \end{aligned} \tag{7}$$

After substituting $Z(\varepsilon_i) = -\frac{1}{\varepsilon_i} - \frac{1}{2\varepsilon_i^3}$, $n_{oi} = n_{oe}$ and multiplying throughout by $\frac{k_\perp^2 \lambda_{\text{Di}}^2}{\eta_i}$

$$\begin{aligned} 0 = &\frac{\lambda_{\text{Di}}^2}{\lambda_{\text{De}}^2}\frac{\eta_e}{\eta_i}\frac{T_{\perp e}}{T_{||e}} + \left[\frac{T_{\perp i}}{T_{||i}} - \Gamma_0(\mu_i)\frac{T_{\perp i}}{T_{||i}} + \frac{\Gamma_0(\mu_i)k_\perp}{2k_{||}}\right. \\ &\varepsilon_n \rho_i \frac{\alpha_{\perp s}}{\alpha_{||s}}\frac{k_{||}\alpha_{||i}}{\overline{\omega} - n\Omega_i + k_\perp \Delta'} - \frac{\Gamma_0(\mu_i)k_\perp}{k_{||}}\frac{n\Omega_i + k_{||}\alpha_{||i}}{\overline{\omega} - n\Omega_i + k_\perp \Delta'} \\ &-\frac{\Gamma_0(\mu_i)k_\perp}{2(\overline{\omega} - n\Omega_i + k_\perp \Delta')^2}\cdot\frac{T_{\perp i}}{T_{||i}}\left(k_{||}\alpha_{||i}\right)^2\left(1 - \frac{k_\perp}{k_{||}}A_i\right) \\ &\left.-\frac{\Gamma_0(\mu_i)k_\perp}{2}\frac{\varepsilon_T \rho_i \alpha_{\perp i}}{\overline{\omega} - n\Omega_i + k_\perp \Delta}\right] \end{aligned} \tag{8}$$

where

$$\eta_i = 1 - \frac{\overline{E'}(x)}{4\Omega_i^2}$$

$$\eta_e = 1 - \frac{\overline{E'_e}(x)}{4\Omega_e^2}$$

Multiplying throughout in Equation (8) by $\left(\frac{\overline{\omega}-n\Omega_i+k_\perp\Delta'}{k_{||}\alpha_{||i}}\right)^2$ we obtain a quadratic dispersion as:

$$a_1\left(\frac{\overline{\omega'}}{\Omega_i}\right)^2 + b_1\left(\frac{\overline{\omega'}}{\Omega_i}\right) + c_1 = 0 \tag{9}$$

where

$$a_1 = \left[a_2 - \Gamma_0\left(\mu_i\right)\right]\frac{1}{\overline{k^2}}$$

$$a_2 = \frac{\eta_e}{\eta_i}\frac{T_{\perp i}}{T_{||i}} + \frac{T_{\perp i}}{T_{||i}} - \Gamma_0\left(\mu_i\right)\frac{T_{\perp i}}{T_{||i}}$$

$$b_2 = \frac{\Gamma_0\left(\mu_i\right)k_\perp}{2k_{||}}\varepsilon_n\rho_i\frac{\alpha_{\perp i}}{\alpha_{||i}} - \frac{\Gamma_0\left(\mu_i\right)k_\perp}{2k_{||}} - \frac{\Gamma_0\left(\mu_i\right)k_\perp n\Omega_i}{2k_{||}^2\alpha_{||i}}$$

$$b_1 = \frac{\Omega_i}{k_{||}\alpha_{||i}}b_2 - \frac{2k_\perp\Delta'}{k_{||}^2\alpha_{||i}^2}a_2\Omega_i$$

$$c_1 = \frac{\Gamma_n\left(\mu_i\right)T_{\perp i}}{2T_{||i}}\left(1 - \frac{k_\perp}{k_{||}}A_i\right) - \frac{b_2 k_\perp\Delta'}{k_{||}\alpha_{||i}} + \frac{k_\perp^2\Delta'^2}{k_{||}^2\alpha_{||i}^2}$$

$$\overline{\omega'} = \overline{\omega} - n\Omega_i$$

$$\Delta' = \frac{\partial\Delta}{\partial t}$$

$$A_i = A_s = \frac{1}{\Omega}\frac{1\partial v_{0z}(x)}{\partial x}$$

$$E(x) = E_{0x}\left(1 - \frac{x^2}{a^2}\right)$$

The solution of Equation (8) is

$$\overline{\omega'} = -\frac{b_i}{2a_i}\left[1 \pm \left(1 - \frac{4a_i c_i}{b_i^2}\right)\right] \tag{10}$$

From this expression dimensionless growth rate has been calculated by computer technique when $b_i^2 < 4a_i c_i$. Hence this criteria gives a condition for the growth rate of wave.

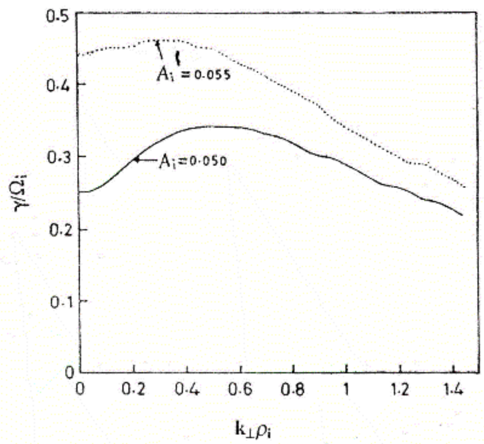


**Figure 1.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp\rho_i$ for different values of shear scale length $A_i$ and for other fixed parameters [$B_0 = 6\times10^{-7}$ T, $E_{0x} = 4 \times 10^{-3}$ m V/m, $A_T = T_{\perp i}/T_{||i} - 1 = 0.25$, $T_e/T_i = 4$, $\theta = 88°$, $P/a = 0.5$, $\varepsilon_n\rho_i = 0.02$].

## 3. RESULT AND DISCUSSION

Growth rate variations with $k_\perp\rho_i$ were calculated from expression for various values of plasma parameters listed in figure captions. In Figure 1, the growth rate increases by increasing the velocity shear scale length but maxima shifted towards lower values of $k_\perp\rho_i$. The mechanism for instability of this mode is due to coupling of regions of positive and negative wave energy. This coupling occurs if velocity shear is non-uniform and the shear is the source of energy. Figure 2 deals with variation of growth rate with $k_\perp\rho_i$ for different values of $\tan\theta = k_\perp/k_{||}$. The growth rate increases by increasing values of theta from 87° to 88.5° but maxima coincide for a fixed value of $k_\perp\rho_i$. In Figure 3, the inhomogenity in electric field affects the growth rate. Increases by increasing the value of $p/a = x/a^2$ and maxima slightly shifts for lower values of $k_\perp\rho_i$. Ion-cyclotron turbulence and frequencies nearer to this have been observed with shocks [32] in the magnetosphere and where localized field perpendicular to the magnetic field is present. Inhomogenity in magnetic field introduces a shear in velocity flow and couples positive and negative energy waves leading to growth of the wave. In Figure 4, the growth rate is affected by the ratio of $T_e/T_i$. It is decreased by increasing the value of $T_e/T_i$ and maxima shifts towards higher values of $k_\perp\rho_i$ as the velocity shear term is proportional to $T_e/T_i$. When shear flow is dominated by electron flow, the maxima

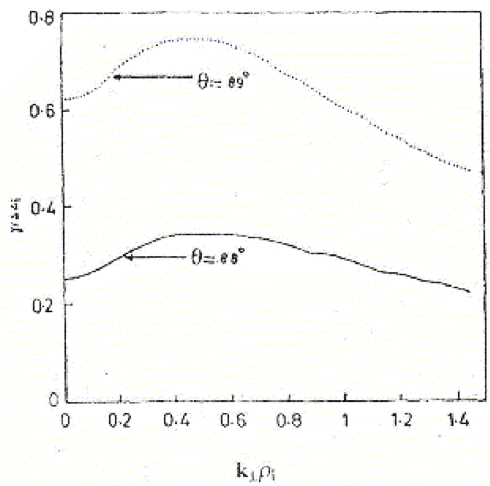


**Figure 2.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp \rho_i$ for different values of $\theta(=\tan^{-1} k_\perp/k_{||})$ and for other fixed parameters [$B_0 = 6 \times 10^{-7}\,\mathrm{T}$, $E_{0x} = 4\times10^{-3}\,\mathrm{m\,V/m}$, $A_T = T_{\perp i}/T_{||i} - 1 = 0.25$, $T_e/T_i = 4$, $A_i = 0.05$, $P/a = 0.5$, $\varepsilon_n \rho_i = 0.02$].

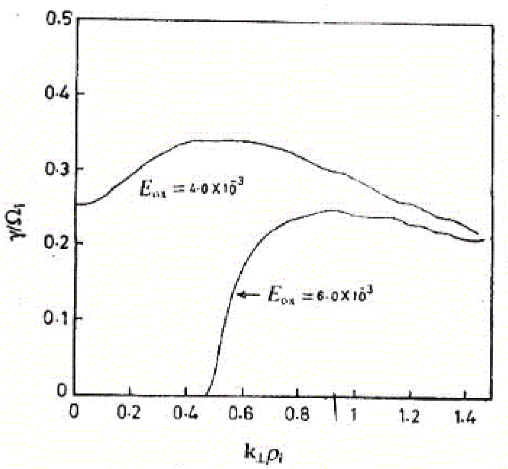


**Figure 3.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp \rho_i$ for different values of magnituse of electric field $E_{0x}$ and for other fixed parameters [$B_0 = 6 \times 10^{-7}\,\mathrm{T}$, $\theta = 88°$, $A_T = T_{\perp i}/T_{||i} - 1 = 0.25$, $T_e/T_i = 4$, $A_i = 0.05$, $P/a = 0.5$, $\varepsilon_n \rho_i = 0.02$].

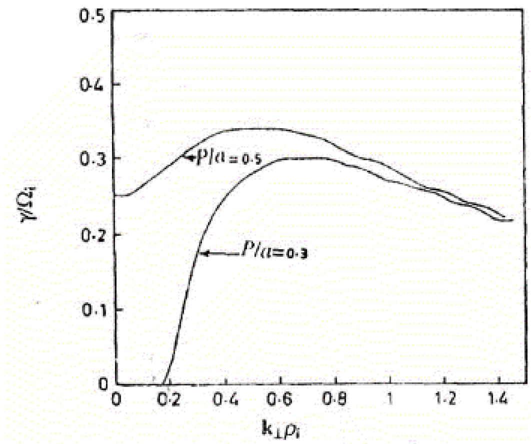


**Figure 4.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp \rho_i$ for different values of inhomogeneity of electric field $P/a$ and for other fixed parameters [$B_0 = 6 \times 10^{-7}\,\mathrm{T}$, $\theta = 88°$, $A_T = T_{\perp i}/T_{||i} - 1 = 0.25$, $T_e/T_i = 4$, $A_i = 0.05$, $E_{0x} = 4 \times 10^{-3}\,\mathrm{m\,V/m}$, $\varepsilon_n \rho_i = 0.02$].

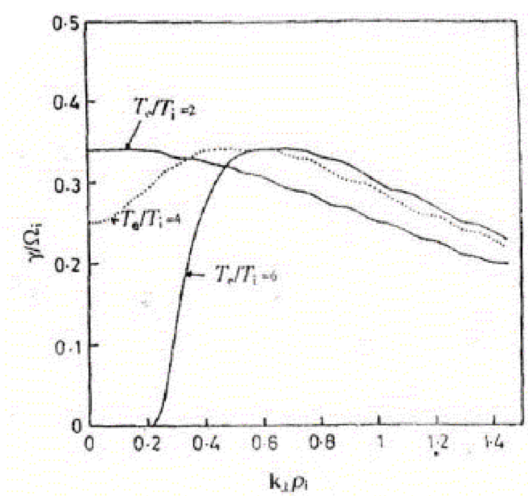


**Figure 5.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp \rho_i$ for different values of temperature ratio $T_e/T_i$ and for other fixed parameters [$B_0 = 6 \times 10^{-7}\,\mathrm{T}$, $\theta = 88°$, $A_T = T_{\perp i}/T_{||i} - 1 = 0.25$, $P/a = 0.5$, $A_i = 0.05$, $E_{0x} = 4 \times 10^{-3}\,\mathrm{mV/m}$, $\varepsilon_n \rho_i = 0.02$].

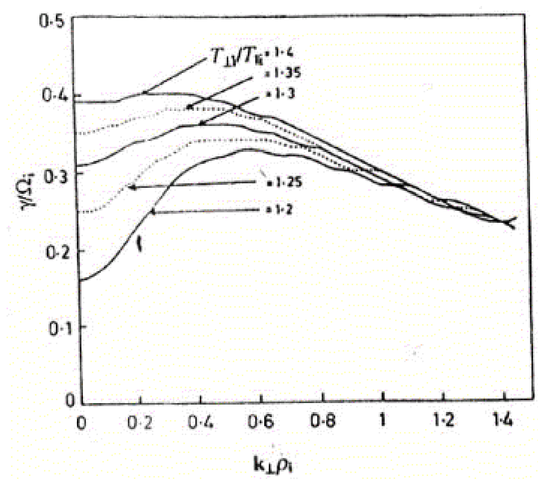


**Figure 6.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp\rho_i$ for different values of temperature anisotropy $A_T$ and for other fixed parameters $[B_0 = 6 \times 10^{-7}\,\mathrm{T}$, $\theta = 88^\circ$, $T_e/T_i = 4$, $P/a = 0.5$, $A_i = 0.05$, $E_{0x} = 4 \times 10^{-3}\,\mathrm{m\,V/m}$, $\varepsilon_n\rho_i = 0.02]$.

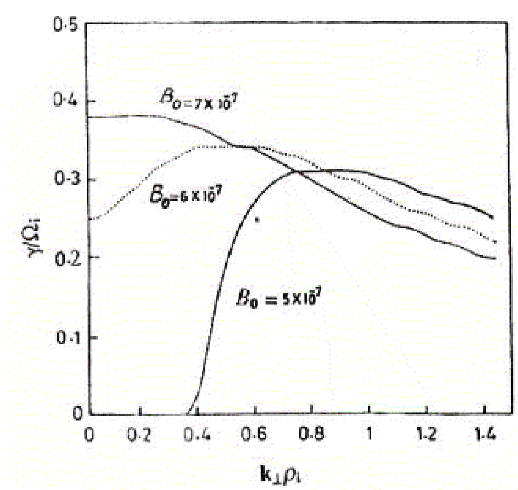


**Figure 7.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp\rho_i$ for different values of magnetic field $B_0$ and for other fixed parameters $[A_T = T_{\perp i}/T_{||i} - 1 = 0.25$, $\theta = 88^\circ$, $T_e/T_i = 4$, $P/a = 0.5$, $A_i = 0.05$, $E_{0x} = 4 \times 10^{-3}\,\mathrm{m\,V/m}$, $\varepsilon_n\rho_i = 0.02]$.

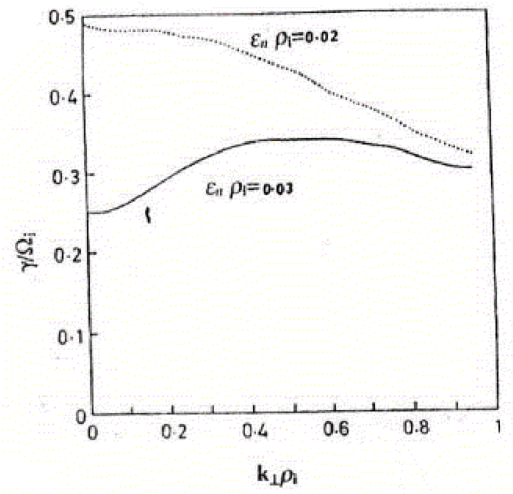


**Figure 8.** Variation of growth rale $\gamma/\Omega_1$ with $k_\perp\rho_i$ for different values of $\varepsilon_n\rho_i$ and for other fixed parameters [$B_0 = 6 \times 10^{-7}$, $\theta = 88°$, $T_e/T_i = 4$, $P/a = 0.5$, $A_i = 0.05$, $E_{0x} = 4 \times 10^{-3}\,\mathrm{m\,V/m}$, $A_T = T_{\perp i}/T_{||i} - 1 = 0.25$].

flows towards lower wavelengths [17]. In Figure 5, the growth rate increase by increasing the value of ion perpendicular and parallel temperature ratio for and maxima shifts towards lower values of $k_\perp\rho_i$. The instability criterion indicates that velocity shear is proportional to $T_e/T_i$ and ion perpendicular and parallel temperature ratio. The non-isothermal plasma changes the velocity shear required for onset of this instability. In Figure 6, the effect of temperature gradient on growth rate has been shown. The growth rate decreases by increasing the value of temperature gradient scale length but the maxima shift towards lower values of $k_\perp\rho_i$. The temperature gradient has weak stabilizing effect on shear driven K-H instability. If the temperature gradient is weaker than electron density gradient than it is having stabilizing effect. However, in case of large temperature gradient in perpendicular direction increases the growth rate. It shows the establishing nature in K-H instability for $\beta i > 1$. In Figure 7, the growth rate increase by increasing the value of density gradient initially. However for much larger density gradients, the growth rate decreases. This mode is not stabilized even for strongest density gradient equaling to velocity shear scale length. The effect of magnetic field gradient has very weak effect on the growth as shown in Figure 8. This effect would be of importance when electromagnetic effects are included in. In general this has a stabilizing effect introducing resonant and non-resonant interactions affecting the growth rate and real frequency.

## 4. CONCLUSION

Velocity shear ,electron ion temperature ratio, temperature anisotropy and in homogeneity in electric field are found to be dominating sources for K-H instability. The density gradient has destabilizing effect on K-H mode where as temperature and magnetic field gradient are found to be have weaker effect on this instability.

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## REFERENCES

1. Axford, W. I. and C. O. Hines, "A unifying theory of high latitude geophysical phenomena and geomagnetic storms," *Can. J. Phys.*, Vol. 39, 1433, 1961.
2. Mishra, S. P., K. D. Misra, and R. N. Singh, "Stability of magnetopause boundary and generation of long period geomagnetic pulsations," *Pramana*, Vol. 6, 77, 1976.
3. Mishra, S. P. and K. P. Misra, "Role of Kelvin-Helmholtz instability in ionospheric phenomena," *Indian J. Radio and Space Phys.*, Vol. 5, 250, 1976.
4. Mishra, S. P. and K. D. Misra, "Kelvin-Helmholtz instability in a magneto-plasma," *IEEE Transaction on Plasma Sci.*, Vol. 6, 355, 1978.
5. Yumoto, K. and T. Saito, "Hydromagnetic waves driven by velocity shear instability in the magnetispheric boundary layer," *Planet Space Sci.*, Vol. 28, 789, 1980.
6. Walkar, A. D. M., "The Kelvin-Helmholtz instability in the low-latitude boundary layer," *Planet Space Sci.*, Vol. 29, 1119, 1981.
7. Cowley, S. W. H., D. J. Southwoo, and M. A. Saunders, "Interaction of magnetic field perturbations in the earth's magnetic boundary layers," *Planet Space Sci.*, Vol. 31, 1237, 1983.
8. Takahashi, K. and R. L. McPherron, "Standing hydro magnetic oscillations in the magnetosphere," *Planet. Space Sci.*, Vol. 34, 1223, 1984.

9. Kivelson, M. G. and Z.-Y. Pu, "The Kelvin-Helmholtz insatability on the magnetopause," *Planet Space Sci.*, Vol. 32, 1335, 1984.
10. Uberoi, C., "On the Kelvin-Helmholtz instability of structured plasma layers in the magnetosphere," *Planet Space Sci.*, Vol. 34, 1223, 1984.
11. Basu, B. and B. Coppi, "Velocity shear and fluctuations in the auroral regions of the ionosphere," *J. Geophys. Res.*, Vol. 94, 5316, 1989.
12. Eastman, T. E., S. A. Fuselier, and J. T. Gosling, "Magnetopause crossing without aboundary layer," *J. Geophys. Res.*, Vol. 101, 49–57, 1996.
13. Omidi, N. and D. Winske, "Structure of the magnetopause inferred from one-dimensional hybrid simulations," *J. Geophys. Res.*, Vol. 100, 11935–11955, 1995.
14. Sotirelis, T., "The shape and field of the magnetopaure as determined from pressure balance," *J. Geophys. Res.*, Vol. 1001, 15255, 1996.
15. Pu, Z.-Y., "Kelvin-Helmholtz instability in collisionless space plasmas," *Phys. Fluids B*, Vol. 1, 440, 1989.
16. Romero, H., G. Ganguli, Y. C. Lee, and P. J. Palmadesso, "Electron-ion hybrid instabilities driven by velocity shear in a magnetized plasma," *Phys. Fluids B*, Vol. 4, 1708, 1992.
17. Wang, Z., P. L. Pritchett, and M. Ashour-Abdalla, "Kinetic effects on the velocity shear driven instability," *Phys. Fluids B*, Vol. 4, No. 5, 1092, 1992.
18. Thomas, V. A. and D. Winske, "Kinetic simulations of the Kelvin-Helmholtz instability at the magnetopause," *J. Geophys. Res.*, Vol. 98, 11425, 1993.
19. Fujimoto, M. and T. Terasawo, "Anomalous ion mixing within an MHD scale Kelvin-Helmholtz vortex," *J. Geophys. Res.*, Vol. 99, 8601, 1994.
20. Nishikawa, K. I., G. Ganguli, Y. C. Lee, and P. J. Palmadesso, "Simulation of ion-cyclotron like modes in a magnetoplasma with transverse imhomogeneous electric field," *Phys. Fluids*, Vol. 31, 1568, 1988.
21. Tajma, T., W. Horton, P. J. Monison, J. Schutkeker, T. Kaminura, K. Mina, and Y. Abe, "Instabilities and Vortex dynamics in shear flow of magnetized plasmas," *Phys. Fluids B*, Vol. 3, 938, 1991.
22. Thomas, V. A., "Kinetic simulation of the Kelvin-Helmholtz instability in a finite sizedjet," *J. Geophys. Res.*, Vol. 100, 12011–12016, 1995.

23. Thomas, V. A., "Three-dimensional kinetic simulation of the Kelvin-Helmholtz instability," *J. Geophys. Res.*, Vol. 100, 19429–19433, 1995.
24. Huba, J. D., "The Kelvin-Helmholtz instability in inhomogeneous plasmas," *J. Geophys. Res.*, Vol. 86, 3653, 1981.
25. Pritchett, P. L. and F. V. Coroniti, "The collisionless macroscopic Kelvin-Helmholtz instability. 1. Transverse electrostatic mode," *J. Geophys. Res.*, Vol. 89, 168, 1984.
26. Cai, D., L. R. O. Story, and T. Neubert, "Kinetic equilibria of plasma shear layers," *Phys. Fluids B*, 273, 1990.
27. Lemons, D. S., D. Winske, and S. P. Gary, "Electrostatic ion-velocity shear instability," *J. Geophys. Res.*, Vol. 97, 19381, 1992.
28. Pandey, R. S., K. D. Misra, and A. K. Tripathi, "Kelvin-Helmholtz instabilityin an anisotropic magneto-plasma in the presence of inhomogeneous perpendicular electric field and parallel flow velocity shear," *Indian Journal of Radio and Space Physics*, Vol. 30, 113–120, 2001.
29. Pandey, R. S., K. D. Misra, and A. K. Tripathi, "Generation of electrostatics ion-cyclotron like wave by parallel flow velocity shear in the presence of inhomogeneous electric field in an anisotropic magneto-plasma," *Indian Journal of Radio & Space Physics*, Vol. 30, 75–82, 2003.
30. Misra, K. D. and R. S. Pandey, "Generation of whistler emission by injection of hot electrons in presence of perpendicular a.c. electric field," *J. Geophys. Res.*, Vol. 100, 19405, 1995.
31. Gary, S. P. and S. J. Schwartz, "An electrostatic flow shear instability," *J. Geophys. Res.*, Vol. 85, 2978, 1980.
32. Huang, H., Y. Fan, B. Wu, F. Kong, and J. A. Kong, "Surface modes at the interfaces between isotropic media and uniaxial plasma," *Progress In Electromagnetics Research*, PIER 76, 1–14, 2007.
33. Kudrin, A. V., E. Yu. Petrov, G. A. Kyriaeou, and T. M. Zaboronkova, "Insulated cyclindrical antena in cold magnetoplasma," *Progress In Electromagnetics Research*, PIER 53, 135–166, 2005.
34. Pandey, R. S., R. P. Pandey, K. M. Singh, and N. M. Mishra, "Cold plasma injection on VLF wave mode for relativistic magnetoplasma with a.c. electric field," *Progress In Electromagnetics Research C*, Vol. 2, 217–232, 2008.
35. Pandey, R. S., R. P. Pandey, A. K. Srivastava, S. M. Karim, and Hariom, "Electromagnetic ion-cyclotron instability in presence

of a.c. electric field for Lorentzian Kappa," *Progress In Electromagnetics Research M*, Vol. 1, 207–217, 2008.

36. Pandey, R. S., U. C. Srivastava, R. P. Pandey, B. B. Prasad, and Hariom, "Velocity shear ion cyclotron instability with perpendicular a.c. electric field," *Progress In Electromagnetics Research M*, Vol. 3, 177–199, 2008.