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The Effect of Suspended Particles on the Acoustic Mode of Molecular Gas

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Abstract

In the present problem, we will investigate the effect of suspended particles on the stability of hydrogen gas where atomic component of gas is being transformed into molecule or solid state. The study of propagation of sound and thermal waves in a non-reacting fluid is carried out. The fluid is assumed to be cooled or heated by non-specified by a heat loss function $L(\rho, T)$. Thermal condition is taken into account. The stability criterion is deduced with linear perturbation theory similar to Field analysis.The conditions of stability and instability has been derived from the relevant dispersion relation under varying assumptions.

Key words : Suspended particles, Dispersion relation, Stability, Instability, Fluid, Heat loss function, Linearization.

Introduction

Many processes arise in the star formation and collapse of interstellar clouds and there are many models in an attempt to solve this problem. Recently, Alfven and Cech (1) have showed that the model for all such systems should start from the assumption that a magnetized central body was formed already and surrounded by a dusty plasma from which cloudlets of different composition wit dust grains fall in towards it.

The thermal instability of uniform, static, optically thin medium has been studied by Field (2) which occurs due to density and temperature dependence of heat loss function L defined as energy losses minus energy gains per gram per second. Concerning the processes leading to condensation of interstellar gas. Spitzer (3) has suggested the possibility of some other thermal instabilities: instability due to change of ionization degree, instability associated with the cooling rate in the state of cooling excess, instability due to formation of molecules and/or solid particles.

In this direction, Defouw (4) and Goldsmith (5) have investigated the stability of the pure hydrogen plasma and of the interstellar gas respectively. They have assumed the dependence of ionization degree on heat loss function along with the dependence of density and temperature. Thus, we find that heat loss function is an important parameter in defining the gravitational collapse of gas or molecular cloud. Hunter (6) has discussed the thermal instability of gas flow. Takayanagi and Nishimura (7) have shown that the molecular hydrogen is an effective coolant in a certain range of temperature. If a temperature – increase is accompanied by a decrease in number fraction of molecular hydrogen, cooling becomes less effective. We also find that in the case of condensation of solid H_2, an instability would appear because of drop of gas pressure due to decrease of number density.

Objectives

In this section the study of propagation of sound and thermal waves in a non-reacting fluid is carried out. The effect of suspended particles are also incorporated in this analysis. The fluid is assumed to be cooled or heated by non-specified processes which can be representedby a heat loss functionL(ρ,T). Thermal conduction is taken into account. The conditions of stability and instability have been derived from the relevant dispersion relation under varying assumptions.

Equations of the Problem :

The full set of well known gas dynamic equations are :

$$\frac{d\rho}{dt} + \rho\vec{\nabla}\cdot\vec{v} = 0, . \qquad (1)$$

$$\rho\frac{d\bar{v}}{dt}+\nabla p-K'n\,(\bar{u}-\bar{v})=0, \quad (2)$$

$$\frac{d\bar{u}}{dt}-\frac{K'n}{p}\,(\bar{\nabla}-\bar{u})=0, \quad (3)$$

$$\frac{\partial n}{\partial t}+\nabla\cdot(n\,\bar{u})=0, \quad (4)$$

$$p=\frac{R}{\mu}\,\rho T, \quad (5)$$

$$\frac{R}{\mu(r-1)}\frac{dT}{dt}-\frac{P}{\rho^2}+L(\rho,T)-\frac{1}{\rho}\nabla\cdot(\theta\nabla T)=0, \quad (6)$$

We assume perturbations of the form

$$A\,(x,t)=A_1\exp\,(\omega t+ikx), \quad (7)$$

operator $\frac{\mathrm{d}}{\mathrm{dt}}$ is the substantial derivative given by :

$$\frac{d}{dt}=\frac{\partial}{\partial t}+\vec{v}\cdot\bar{\nabla}.$$

The initial state of the system, denoted by the subscript '0' is taken to be a quiescent layer with a uniform particle distribution. Hence

$$\mathrm{v}_0=\mathrm{u}_0=0,\ \mathrm{n}_0=\mathrm{const.} \quad (8)$$

The perturbations in density, velocity, pressure and temperature is given by ρ_1, v_1, P_1 and T_1 respectively.

The perturbed state is given by:

$$\rho=\rho_0+\rho_1$$

$$\mathrm{p}=\mathrm{p}_0+\mathrm{p}_1 \quad (9)$$

Using equations (7) – (9) in all above (1) – (5) equations and then linearizing them by neglecting the higher order perturbations. Suffix '0' is omitted from the equilibrium quantities.

Linearized Perturbation Equations :

$$\omega\rho_1+ik\rho\,v_1=0 \quad (10)$$

$$ikp_1+\rho\omega v_1+\frac{K'n\tau}{\beta}\omega v_1=0, \quad (11)$$

$$\frac{R}{\mu(\gamma-1)}\omega T_1-\frac{R}{\mu}\frac{T}{\rho}\omega\rho_1+\frac{1}{\rho}\theta\,k^2T_1+L_\rho\rho_1-L_TT_1=0, \quad (12)$$

$$\frac{p_1}{p} - \frac{T_1}{T} - \frac{\rho_1}{\rho} = 0, \quad (13)$$

Where

$\tau = m/k$ relaxation time

$$\beta = (\tau\omega + 1) \quad .(14)$$

Dispersion Relation:

$$\omega^4 \tau + \omega^3 \left\{ 1 + \frac{K'n\tau}{p} + \frac{\mu(r-1)}{R} \tau \left(L_T + \frac{\theta k^2}{\rho} \right) \right\}$$

$$+ \omega^2 \left[\frac{\mu(\gamma-1)}{R} \left(L_T + \frac{\theta k^2}{\rho} \right) \frac{K'n\tau}{\rho} + \frac{\mu(\gamma-1)}{R} \right.$$

$$\left. \left(L_T + \frac{\theta k^2}{\rho} \right) + \tau k^2 \frac{P}{\rho} \gamma + \omega \left[\tau k^2 \left\{ T \left(L_T + \frac{\theta k^2}{\rho} \right) - \rho L_\rho \right\} (\gamma - 1) + \frac{k^2 p \gamma}{\rho} \right] \right.$$

$$+ (\gamma - 1) \left[T \left(L_T + \frac{\theta k^2}{\rho} \right) - \rho L_\rho \right] k^2 = 0. \quad (15)$$

This is fourth order dispersion relation which represent the combined effect of the thermal conductivity, heat loss function and suspended particles on the wave propagation in the medium.

Discussion :

Now we will discuss the dispersion relation (15) under various assumptions and simplification. If we neglect the effect of thermal conductivity i.e., $\theta = 0$ in equation (15), we get a fourth degree equation of ω and from the constant term of new equation we may obtain the condition of instability

$$[TL_T - \rho L_\rho] < 0 \quad (16)$$

It we put L_ρ & L_T equal to zero in equation (15) we get the usual acoustic mode of propagation of molecular gas which is

$$\omega^2 + c^2 k^2 = 0,$$

From equation (15) of our basic problem, we may find out the condition of instability from constant term.

Hence, it follow:

$$k = \left\{ \frac{(\rho L_\rho - TL_T)\rho}{\theta_T} \right\}^{\frac{1}{2}} \quad (17)$$

and

$$\lambda >> \lambda_k = 2\pi \left\{ \frac{\theta_T}{(\rho L_\rho - T L_T)\rho} \right\}^{\frac{1}{2}},$$

or

$$\lambda >> \lambda_k = 2\pi \left(\frac{\theta_T}{L' \rho} \right)^{\frac{1}{2}} \quad (18)$$

Where

$$L' = (\rho L_\rho - T L_T)$$

From equations (16), (17) and (18) we may say that condition of instability modifies due to thermal conductivity. We also find that there is no effect of the presence of suspended particles on the conditions of instability in both the cases. We find that when thermal conductivity is neglected, the condition of instability in dependent upon heat loss function but when thermal conductivity is present the condition of instability depends upon both heat loss function and thermal conductivity. Thus we conclude about the importance of both thermal conductivity and heat loss function in the case of molecular cloud formation.

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