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ORIGINAL ARTICLE

Rayleigh–Taylor instability in an ionized medium

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Abstract We study the linear theory of the magnetized Rayleigh–Taylor instability in a system consisting of ions and neutrals. Both components are affected by a uniform vertical gravitational field. We consider ions and neutrals as two separate fluid systems that can exchange momentum through collisions. However, ions have a direct interaction with the magnetic field lines but neutrals are not affected by the field directly. The equations of our two-fluid model are linearized and by applying a set of proper boundary conditions, a general dispersion relation is derived for our two superposed fluids separated by a horizontal boundary. We found two unstable modes for a range of wavenumbers. It seems that one of the unstable modes corresponds to the ions and the other one is for the neutrals. Both modes are reduced with increasing particle collision rate and ionization fraction. We show that if the two-fluid nature is considered, the RT instability would not be suppressed and we also show that the growth time of the perturbations increases. As an example, we apply our analysis to the Local Clouds which seem to have arisen because of the RT instability. Assuming that the clouds are partially ionized, we find that the growth rate of these clouds increases in comparison to the fully ionized case.

Keywords Instabilities · Rayleigh · Taylor instability · Magnetohydrodynamics

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1 Introduction

The Rayleigh–Taylor (RT) instability occurs when a heavy fluid is supported by a lighter fluid in a gravitational field, or, equivalently, when a heavy fluid is accelerated by a lighter fluid. The RT instability and the related processes have found applications in various astronomical systems, such as the expansion of supernova remnants (e.g., Ribeyre et al. 2004) (where inertial acceleration plays the role of the gravitational field), the interiors of red giants (e.g., Charbonnel and Lagarde 2010), and radio bubbles in galaxy clusters (Pizzolato and Soker 2006). The evolution of the RT instability is influenced by many different factors. For example, viscosity tends to reduce the growth rate and to stabilize the system (e.g., Chandrasekhar 1961). The growth rate of the short-wavelength unstable perturbations decreases because of the compressibility (e.g., Shivamoggi 2008). A dynamically important radiation field affects RT instability as well (Jacquet and Krumholz 2011). However, the most important effects in the astrophysical context are probably those due to the presence of the magnetic fields. One can decompose the magnetic field lines into a component perpendicular to the interface and a component parallel to it. We will deal only with the effect of a tangential magnetic field.

The incompressible RT instability in a plane parallel to a uniform tangential magnetic field in both fluids has been studied analytically by Chandrasekhar (1961). The linear stability theory shows that a tangential magnetic field slows down the growth rate of the RT instability. The growth rate ω for the modes with wavenumber k_x parallel to the magnetic field lines is given by

$$\omega^2 = \frac{\rho_{02} - \rho_{01}}{\rho_{02} + \rho_{01}} g k_x - \frac{2B^2}{4\pi} \frac{k_x^2}{\rho_{02} + \rho_{01}}. \tag{1}$$