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ORIGINAL ARTICLE

Collisional effect on the Weibel instability in a semi-relativistic anisotropic plasma

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Abstract The detailed properties of the classical electromagnetic Weibel instability in a semi-relativistic anisotropic plasma are investigated for Maxwellian distribution. In this article, the effects of one particular factor affecting the growth rate of Weibel instability, Coulomb collision effect of electrons and ions, is studied and discussed based on the equilibrium semi-relativistic Maxwellian distribution function, in a dense and unmagnetized anisotropic plasma. An analytical expression is derived for the growth rate of the Weibel instability. The two limiting cases ($|\xi| \ll 1$ and $|\xi| \gg 1$) are considered. It is shown that in the limit $|\xi| \ll 1$, the quantity η, which is due to the collision term, will appear in the growth and in the conditions of the rate of the Weibel instability. The quantity χ symbolizes the contribution from relativistic terms which becomes unity as we approach the non-relativistic Maxwellian case, leading to the standard Weibel instability scenario. The increasing of η leads to decreasing of the growth rate, and with the decreasing of η the growth rate will increase.

Keywords Weibel instability · Collisional effect · Semi-relativistic

1 Introduction

The interaction of intense radiation with a plasma leads to a variety of applications, e.g., inertial confinement fusion (Lindl 1995), pulsar emissions (Taylor and Huguenin 1971) and instabilities (Ashby and Paton 1967; Tautz and Sakai 2007). These instabilities are responsible for the turbulent electromagnetic fields and can be electromagnetic as well as electrostatic. The well-known classical Weibel instability due to temperature anisotropy or momentum anisotropy is a kind of electromagnetic instabilities. Weibel (1959) first calculated the spontaneously growing transverse waves in a plasma with anisotropic velocity distribution. The Weibel instability has wide-ranging applications both in astrophysical plasmas and laboratory plasmas (Medvedev 2007; Silva et al. 2003). As is well known, it can explain the generation of magnetic field in the vicinity of gamma ray burst sources, supernovae, and galactic cosmic rays. In the simple case of unmagnetized plasma, this instability has been extensively studied in both the relativistic and non-relativistic regimes. It is generally thought that collisional effects on the Weibel instability (Zaheer and Murtaza 2007) or the current-filamentation instability (CFI) (Califano and Bulanov 1997) are significant for the transport and energy deposition of a large flux of relativistic electron beam penetrating a plasma and alter this instability (Hao et al. 2009). The collision-less Weibel instability is like a variety of mechanisms for producing the up-stream magnetic fields (Shvets and Khudik 2009). A lot of work on collision-less cases has been done in non-relativistic and relativistic regions (Shokri 2004; Mahdavi 2013). In this paper, the electron–ion Coulomb collision effect is studied based on the semi-relativistic Maxwellian distribution for an anisotropic plasma. The article is organized as follows. First in Sect. 2, we introduce the kinetic physical description of the Weibel instability and obtain the analytical expression of the collisional effect on the Weibel instability. Next, a numerical analysis is introduced to carefully investigate the electron–ion Coulomb collision effect on the Weibel instability in a semi-relativistic anisotropic plasma in Sect. 3. Finally, a summary and conclusion are presented in Sect. 4.

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