

Letter

Philosophy of Weibel Instability in Laser Fusion Plasma

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Abstract: In this work, have put forward a philosophy of the Weibel instability in laser fusion plasma; these instabilities generated by several mechanisms, namely: the heat transport, the expansion of the plasma and the inverse bremsstrahlung absorption (IB). Several research papers have been presented as well as theoretical models for the relaxation and stability of these modes, which are considered to be very flammable and peaceful on the interaction yield between lasers and plasma. To resolve these modes must be combined with the magnetic field. The stabilization effect due to the coupling of the self-generated magnetic field by Weibel instability with the laser wave field is explicitly showed in recently paper. In these studies, the relativistic and non-relativistic or linear and non-linear effects are taken into account here; the basic equation is the Fokker-Planck (F-P) or Vlasov equation. The best result is that the coupling of self-generated magnetic field with the laser wave causes a stabilizing effect of excited Weibel modes in the all states. Found a decrease in the spectral range of Weibel unstable modes. This decreasing is accompanied by a reduction of orders in the growth rate of instability or even stabilization of these modes. It has been shown that the previous analysis of the Weibel instability due to IB have overestimated the values of the generated magnetic fields.

Keywords: Relativistic and Non-relativistic Weibel Instability, Laser Fusion Plasma, Static Magnetic Field, Stabilization, Laser Plasma Interaction

1. Introduction

Several authors have made the case that Weibel instability can and should be taught to undergraduate physics students [1-5] and many other articles can be found offering advice in this endeavor [6, 7]. Surely another important two components of good teaching are to identify the subtle areas and to present them clearly using careful mathematic method. In this short article focus on the Weibel instability as an important example.

Weibel instability [1] is a micro-convective instability; are known as electromagnetic growing modes, it corresponds to the excitation of electromagnetic modes in plasmas characterized by temperature anisotropy. In a microscopic way, this corresponds to plasma described by an anisotropic distribution function in velocity space. The temperature anisotropy can be generated in plasma by different mechanisms, specifically the heat transport, the expansion of

the plasma, and the inverse bremsstrahlung absorption [2]. We aim in this work to investigate the Weibel instability due to inverse bremsstrahlung absorption taking into account the stabilization effect due to the coupling of the self-generated magnetic field by the Weibel instability with the laser wave field in the relativistic regime. This needs to derive the dispersion relation of low-frequency electromagnetic Weibel modes in plasma heated by a laser pulse. The basic equation in this investigation is the Fokker-Planck equation with ameliorated Krook collisions term [3, 8]. It results highlight new terms in the dispersion relation, due to the coupling between the laser electric field and the resulting magnetic field by the Weibel instability. These terms contribute to the instability and the convection of Weibel modes. Consider inhomogeneous plasma in interaction with a high frequency and low magnitude laser field. We calculate the distribution function from the anisotropic Fokker-Planck equation [9]. For this use the method of separation of time scales and the

iterative method. After, solve the linear part of the Fokker-Planck equation associated with the disruption of the distribution function and establish the dispersion relation of the Weibel modes. Solving the dispersion relation leads to the calculation of the instability growth rate. The present work is organized as follows: in section 2, we present the interpretation of the Weibel instability and our theoretical model which is the Fokker-Planck equation. In section 3 and 4 we present a discussion of results and a brief conclusion summarizing our main results is given.

2. Interpretation of the Weibel Instability

The interaction of intense radiations with plasmas leads to a variety of applications e.g. inertial confinement fusion, pulsar emissions and instabilities. These instabilities are responsible for the turbulent electromagnetic fields. These instabilities can be both electrostatic as well as electromagnetic in nature?

The Weibel plasma instability has a wide range of applicability in astrophysical plasmas as in

Ref [10, 11], as well as laboratory plasmas. 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 nonrelativistic regimes.

In 1989, Yoon generalized the work of Yoon and Davidson to relativistic bi-Maxwellian plasma [12]. Rolffs et al have described the kinetic Weibel instability in relativistic plasmas for arbitrary distribution functions and gave comparison with the previous works on bi-Gaussian distribution functions [13]. Recently, Califano et al. have carried out investigations of Weibel instability, where the role of temperature anisotropy is taken by two counter streaming electron populations [14]. But Davidson investigated the multispecies Weibel instability for the intense ion and charged beam propagation through background plasma. In our work from Weibel instability in the non-relativistic and relativistic case we describe fully ionized plasma where interactions between particles are dominated by the Coulomb interactions, it is judicious to use the Fokker-Planck equation given in the Ref [15].

In ref [16] a numerical scheme for the Weibel instability of low temperature has been developed which is a modification of the Darwin model. This model neglects the ion contribution and the theoretical model used considers homogeneous plasma in the presence of a wave low amplitude laser in the dipole approximation using the formalism of kinetic theory. In this study the coupling of the magnetic field generated by self-instability with the laser-wave field is taken into account, who holds account of the term of coupling the quasi-static magnetic field with the high frequency field the laser wave, has been established more specifically, typical physical parameters in the experiments melting by laser and plasma for low temperature; it has been revealed a reduction in the spectral range of the unstable modes and a reduction of two orders of magnitude

of the rate instabilities.

In ref [17] the present work has the aim to investigate the non-relativistic Weibel instability induced by inverse bremsstrahlung in laser fusion plasma, where the effect of the self-generated magnetic field is induced. Specifically, we have considered the generated static magnetic field effect on the inverse bremsstrahlung absorption. For this, consider a homogeneous under dense plasma in interaction with a high-frequency and low-magnitude laser electric field. In our investigation, the unperturbed anisotropic distribution function which takes into account the plasma heating due to inverse bremsstrahlung absorption of laser energy is calculated from the Fokker-Planck equation. By using this distribution function; have established the dispersion relation of the Weibel modes taking into account the coupling term of quasi-static magnetic fields with high frequency fields of the laser wave. The main obtained result is that the inclusion of the self-generated magnetic field in the inverse bremsstrahlung absorption causes a decrease of the spectral range of the Weibel unstable modes and a reduction of the growth rate of the instability by two orders.

In ref [4] the Weibel instability is theoretically studied using the Fokker-Planck equation by considering the Krook collisions model. In the non-relativistic case again. The dispersion relation of the Weibel modes is explicitly established under some justified approximation in the laser-fusion experiments [18, 19]. Taking into account to stabilization effect by the inclusion of the coupled term, led to a significant reduction in the Weibel instability growth rate. Numerical treatment of model equations shows that the growth rate of the most unstable Weibel mode decreases by two orders of magnitude. This decrease in the growth rate magnitude is accompanied by a greater reduction in the spectral range of instability. For high density plasma, the Weibel modes become completely stables.

In the ref [5] the Weibel instability due to inverse bremsstrahlung (IB) absorption in laser fusion plasma has been investigated. The stabilization effect due to the coupling of the self-generated magnetic field by Weibel instability with the laser wave field is explicitly showed. In this study, the relativistic effects are taken into account here the basic equation is the relativistic Fokker-Planck equation. The main obtained result is that the coupling of self-generated magnetic field with the laser wave causes a stabilizing effect of excited Weibel modes. We found a decrease in the spectral range of Weibel unstable modes. This decreasing is accompanied by a reduction of two orders in the growth rate of instability or even stabilization of these modes. It has been shown that the previous analysis of the Weibel instability due to (IB) have overestimated the values of the generated magnetic fields.

Recently a new work for Weibel instability has been investigated in a new regime linear and non-linear.

In Ref [20] the bell discussion for the two case of Weibel instability, the linear Weibel instability has been thoroughly investigated, regrettably the same cannot be said of the non-linear behavior including the coupling of electromagnetic and electrostatic effects. The exploration of

the non-linear aspects given here has uncovered a variety of effects that are germane to future investigation for both non-relativistic and relativistic plasmas. While in both the non-relativistic and the relativistic case, the classical constants of motion are total energy and generalized momentum, the problem is to obtain a closed form expression for growth rate in terms of these constants. Because of the coupled effects of the magnetic fields and the electrostatic fields such appears not to be an easily tractable problem as shown in text.

It has been shown previously that Weibel isolated modes (which, subsequently, can develop solution modes) are retained in analytical calculations even if one allows for “classic” extended unstable wavenumber ranges. Because such structures develop only in asymmetric plasmas, they serve as an indicator for the asymmetry of the particle distribution function. This result is very important compared by the work given by V Mikhail in the ref [21] that the quasi-nonlinear approach to the Weibel instability is not efficient, shown that this effect of the plasma “quasi-collisionality” can strongly affect the growth rate and evolution of the Weibel instability in the deeply nonlinear regime.

3. Discussion

All This result shows clearly that the previous analyses of the Weibel instability due to inverse bremsstrahlung have an overestimated for the values of the generated static magnetic fields. Between relativistic and non-relativistic case or linear, quasi-nonlinear and non-linear regime. Therefore, inverse bremsstrahlung overestimated the values of the generated static magnetic fields should not affect the experiences of inertial confinement fusion. The generation of magnetic fields by the Weibel instability due to inverse bremsstrahlung should not affect the experiences of inertial confinement fusion. Several possible extension of this study are possible; namely the taking into account of the nonlinear effect [22, 23] due to the high intense laser pulse, the taking into account of the relativistic effects due to the using of the powered laser in the laser-fusion experiments. Our investigation is realized in the frame of Fokker-Planck kinetic theory, where the temperature anisotropy corresponds to an anisotropic distribution function.

In Zaheer and Murtaza suppose that the distribution function is a semi-relativistic bi-maxwellian, with parallel temperature, T_{\parallel} and perpendicular temperature, T_{\perp} which is an anisotropic distribution [24] and they find a maximum Weibel growth rate proportional to $\gamma_{max} \sim (1 - \frac{T_{\parallel}}{T_{\perp}})$. This is similar to the original Weibel work (ref 11) in the non relativistic case. However in our paper, the distribution function is not supposed but it is calculated from Fokker-Planck equation by considering the fusion plasma heating by the laser source and the collisions term which corresponds to the laser fusion experiments. The spectra of the growth rate $\gamma(k)$ which give the growth rate of the all the

instables Weibel modes (not only the γ_{max}). The calculated $\gamma(k)$ in our paper, contains two contributions: a Landau damping and an instability source proportional to the second anisotropy of the distribution function developed on the legendre polynomials, f_2 which is proportional to the laser intensity via the term $p_0^2 \sim I$. (e.g In the equation of growth rate of Weibel instability, the term corresponds to a loss term due to Landau damping and to collisions effect; it is dominated by collisions loss in the limit: ($k\lambda_{ei} \ll 1$) while in the non-collisional limit ($k\lambda_{ei} \gg 1$), it is dominated by the Landau damping of electromagnetic modes). This shows clearly that the source of the anisotropy and consequently of the instability is the laser heating and we have calculated these functions along with the WI mathematically and numerically, and have been found to have a significant impact on stability and reduction of its spectrum.

4. Conclusion

In conclusion, the Weibel instability is theoretically studied using the Fokker-Planck equation by collisions model. The dispersion relation of the Weibel modes is explicitly established under some justified approximation in the laser-fusion experiments [25, 26]. Taking into account to stabilization effect by the inclusion of the coupled term; led to a significant reduction in the Weibel instability growth rate. Numerical treatment of model equations shows that the growth rate of the most unstable Weibel mode decreases by two orders of magnitude. This decrease in the growth rate magnitude is accompanied by a greater reduction in the spectral range of instability. For high density plasma, the Weibel modes become completely stables. Therefore, the generation of magnetic fields by the Weibel instability due to inverse bremsstrahlung should not affect the experiences of inertial confinement fusion. Finally, we believe that the scientific community and researchers are able to find mathematical and numerical solutions in various formulas and models to solve the problem of Weibel instability, which would reduce the return of the interaction between laser and plasma to produce thermal fuel in the form of aromatic.

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