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Effect of relativistic nonlinearity on the growth rate of Brillouin instability in the interaction of a short laser pulse with an underdense plasma

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Abstract
This paper studies the Brillouin scattering of an intense short laser pulse in an underdense homogenous plasma by taking into account higher orders of relativistic nonlinearities. The coupled dispersion relations of stimulated Brillouin scattering are obtained in the weakly and strongly coupled regimes and investigated analytically to find the nonlinear temporal growth rate of instability in forward and backward scatters. It is shown that, for both the regimes, the Brillouin backward scattering growth rate increases due to the relativistic nonlinearity.

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1. Introduction

It is well known that the electromagnetic waves are parametrically unstable when they propagate through a plasma [1]. Parametric instabilities have been studied extensively in laser-produced plasmas where stimulated Raman and Brillouin scatterings are two dominant parametric processes [2]. Stimulated scattering always involves a pump laser beam and a frequency-shifted scattered wave, coupled by either molecular vibrational transitions (Raman) or acoustic waves (Brillouin) [3]. Scattered waves may propagate parallel to the pump wave (forward scattering) or opposite to the pump wave (backward scattering) [4]. Research into this area has been possible only within the last few years, with the development of lasers capable of delivering ultra-intense pulses with field strengths sufficient to drive electrons to relativistic velocities. In this regime, the propagation of a laser beam, in an underdense plasma having a frequency smaller than the laser frequency, the fast-igniter concept, in particular, requires an understanding of laser–plasma interaction at relativistic laser intensities [5]. Stimulated Brillouin scattering (SBS) is a very important phenomenon because it transfers almost all the energy to the scattered light and reaches a maximum on backward scattering. In the case of backward SBS, it causes the laser's reflection and an energy loss. SBS has been a concern in inertial confinement fusion applications as a potential cause of decreased laser–target coupling efficiency [6]. In this process, laser light interacts with an ion acoustic wave and is scattered. The scattered wave and laser pump exert a ponderomotive force on the electrons, driving the acoustic wave [7, 8]. In this instability, the density fluctuation which provides the coupling to the scattered light wave is the density fluctuation associated with a low-frequency ion acoustic wave. These fluctuations have a wavelength about three times the wavelength of the laser light and are self-consistently driven by the SBS of the Raman-scattered light wave, which is near its critical density [9]. Brillouin instability can be most simply characterized as the resonant decay of an incident photon with frequency ω_0 and wavenumber k_0 into a scattered photon with frequency ω_s and wavenumber k_s plus an ion acoustic photon. The frequency and wave number matching conditions then are $\omega_0 = \omega_s + \omega$ and $\mathbf{k}_0 = \mathbf{k}_s + \mathbf{k}$, where ω and $\mathbf{k}$ are the frequency and wave number of the ion acoustic wave. Since the frequency of an ion acoustic wave is much less than ω_0, it is clear that this instability can occur throughout the underdense plasma. With the advent of the very-high-power source of electromagnetic radiation, the electron velocity in a plasma may become quite large, comparable to the free space velocity of the light.

