Indian J.Sci.Res. 16(2): 161-164, 2017 ISSN: 0976-2876 (Print)
ISSN: 2250-0138 (Online)

PARAMETRIC INSTABILITY OF HIGH POWER LASER INTO TWO ELECTROSTATIC WAVES IN MAGNETIZED PLASMA

S. P. MISHRA[1]

Department of Physics, K. N. Govt. P. G. College, Gyanpur, Bhadohi-221304, India

ABSTRACT

A big X-mode laser with a strong signal travels straight across the steady magnetic field and breaks down into a short-wavelength electron Bernstein wave and an upper hybrid wave. The change in electron density from the upper hybrid wave connects with the moving velocity caused by the main laser driving the electron Bernstein wave. Both the electron Bernstein wave and the main laser push on the electrons, which helps create the upper hybrid wave sideband.

KEYWORDS: Magnetized Plasma, Upper Hybrid Resonance (UHR), Lower Hybrid Wave (LHW), Electromagnetic Pump, Parametric Decay

Parametric instabilities excited by high-frequency electromagnetic pump waves in magnetized plasmas have been the subject of several theoretical and experimental investigations in past (Pesme *et al.*, 1973; Dorfman and Carter, 2016; Fujiyama *et al.*, 1980; Gusakov and Popov, 2010; Porkolab, 1974; Baek *et al.*, 2013; Agapitov *et al.*, 2015; Hussein and Scales, 1997; Hooke and Bernabei, 1972; Grandal, 1976). Parametric instabilities are nonlinear wave interaction instabilities in which a strong pump wave is sent through a nonlinear medium such as a plasma, a fluid, a mechanical system or a nonlinear optical crystal. The parametric instability in a plasma is a nonlinear interaction in which a pump wave at frequency ω_0 is converted into two waves at frequencies ω and ω_1 with $k_0 = k + k_1$, where k_0, k and k_1 are the wave vectors of corresponding waves. In particular, the problem of parametric decay (Drake *et al.*, 1974; Liu and Tripathi, 1986; Konar and Rai, 1994; Saleem and Murtaza, 1986; Parashar *et al.*, 1996) of an electromagnetic pump wave into a high and a low frequency plasma wave has been studied, and the electromagnetic pump wave is usually assumed to be of ordinary, extraordinary or circular polarization. A simple formalism for the parametric decay of an intense, coherent electromagnetic wave into an electrostatic wave and scattered electromagnetic waves in a homogeneous plasma is developed. (Dodin and Arefiev, 2017) using analytical approximation of the parametric dispersion relation, found results of radio frequency (RF) power threshold not in agreement (a factor of two higher) with data available from PLT experiments. The parametric decay of an upper hybrid wave into an upper hybrid wave and a lower hybrid wave in a two electron plasma. In a plasma with ion temperature greater than the electron temperature, an extraordinary electro-magnetic pump wave can parametrically decay into upper hybrid and electron acoustic oscillations (Arefiev *et al.*, 2017; Ott *et al.*, 1980). It is believed that parametric decay instabilities at the present day electron cyclotron resonance heating (ECRH) power level are possible solely in the electron Bernstein wave heating experiments because of the growth of the amplitude of the pump wave in the vicinity of the upper-hybrid resonance (UHR). The parametric decay of a linearly mode converted Langmuir wave into a Bernstein mode/quasimode and a Langmuir wave sideband. We have an intense X wave propagating perpendicularly to dc magnetic field is unstable with respect to a parametric decay into an electron Bernstein wave and a lower hybrid wave. Their theoretical predictions for growth rate are in reasonable agreement with simulation results (Porkolab, 1982; Dermott *et al.*, 1982; Hiroe and Ikegami, 1967).

Direct parametric decay of an electromagnetic pump wave into a warm upper hybrid wave and a strongly damped low frequency electrostatic quasi-mode which is particularly relevant in tokamaks, was first considered and showed that the parametric decay instability in which an X-mode pump wave decays into a warm upper hybrid wave and an lower hybrid quasi-mode could occur during 1st harmonic X-mode ECRH on the Versator II tokamak, as later confirmed (Okabayashi *et al.*, 1973; Bulyginsky *et al.*, 1984; Pietrzyk *et al.*, 1993). A parametric decay instability at the UHR was first observed in mercury vapour tube discharges throughthe excitation of lower hybrid oscillations by sufficiently strong microwave radiation. Similar observations were reported for linear hot-cathode helium discharges and the FM-I spherator. This type of parametric decay instability was also observed in connection with 1st harmonic ECRH of optically thin plasmas in the Versator II, FT-1 and TCA tokamaks, as well as in the Wendelstein 7-A stellarator. Parametric decay instabilities near the UHR involving lower hybrid daughter waves have additionally been used to confirm the occurrence of O-X-B heating in overdense plasmas of the Wendelstein 7-AS stellarator

[1]**Corresponding author**

and the MAST spherical tokama (Wilhelm *et al.*, 1994; Laqua *et al.*, 1997; Laqua, 2007).

The parametric decay of an upper hybrid wave into an electromagnetic and a lower hybrid wave may be excited in ionospheric modification experiments in which a powerful high frequency radio wave is injected into the ionospheric F-region from ground-based transmitters. An O mode wave launched into the ionosphere around harmonics of cyclotron frequency excites a large-amplitude upper hybrid via resonance instability near the critical layer. The parametric decay of upper hybrid wave into a lower hybrid wave and electromagnetic wave may account for the appearance of downshifted maximum in the spectrum of stimulated electromagnetic emissions. This wave is Landau-damped and causes plasma heating.

In this paper, we study the parametric decay of an X-mode laser pump into an electron Bernstein wave an upper hybrid wave. The frequency of electron Bernstein wave is close to the electron cyclotron frequency. We employ kinetic theory to obtain the response of magnetized electrons to electrons Bernstein wave. For the electron response at upper hybrid frequency, In sec 2, we obtain the linear response of electrons to the pump wave. In sec. 3, we study the parametric coupling and obtain the growth rate of the parametric instability. In sec. 4, we present the discussion.

Pump Response

Consider plasma of electron density n_0^0 immersed in a static magnetic field $B_s\hat{z}$. A laser propagates through it in the X-mode,

$$\mathbf{E}_0 = A_0(\hat{y} - \frac{\varepsilon_{0xy}}{\varepsilon_{0xx}}\hat{x})e^{-i(\omega_0 t - k_0 x)},$$

$$\mathbf{B}_0 = c\mathbf{k}_0 \times \mathbf{E}_0 / \omega_0, \quad (1)$$

The X-mode laser imparts oscillatory velocity $\mathbf{v}_0$ to electrons, governed by

$$-i\omega_0\mathbf{v}_0 + \mathbf{v}_0 \times \omega_c\hat{z} = -\frac{e\mathbf{E}_0}{m}, \quad (2)$$

giving

$$v_{0x} = -\frac{e}{m}\frac{\omega_c A_0}{(\omega_0^2 - \omega_c^2 - \omega_p^2)},$$

$$v_{0y} = -i\frac{e}{m}\frac{(\omega_0^2 - \omega_p^2)A_0}{\omega_0(\omega_0^2 - \omega_c^2 - \omega_p^2)},$$

$$v_{0z} = 0.$$

Using $\mathbf{v}_0$ in the equation of continuity $(\frac{\partial n_0}{\partial t} + \nabla.(n_0^0\mathbf{v}_0) = 0)$, we obtain the density perturbation

$$n_0 = -n_0^0\frac{e}{m}\frac{k_0}{\omega_0}\frac{\omega_c A_0}{(\omega_0^2 - \omega_c^2 - \omega_p^2)}. \quad (3)$$

Parametric Instability

The X-mode laser excites a pair of waves, an upper hybrid wave of potential

$$\phi = Ae^{-i(\omega_0 t - k_x x - k_z z)}, \quad (4)$$

The growth rate turns out to be

$$\gamma = \left[-\frac{\alpha\beta}{\frac{\partial\varepsilon}{\partial\omega}\frac{\partial\varepsilon_1}{\omega_1}}\right]^{1/2} \quad (5)$$

$$= [-\frac{1}{8k^2}(\frac{eA_0}{m\omega c})^2\frac{c^2\omega_c^2(\omega_1 - l\omega_c)^2(\omega^2 - \omega_c^2 - k^2v_{th}^2)^2k_x}{\omega_0\omega_1 l I_l(b)e^{-b}(\omega_0^2 - \omega_c^2 - \omega_p^2)^2}\Delta]^{1/2}.$$

In Fig. 1, we plot the growth rate γ/ω_p as a function of $k_{1\perp}v_{th}/\omega_c$ for the parameters $v_{th}/c = v_{1\perp}/c = 0.1,$ $\omega_c/\omega_p = 0.2, l = 1.$ We vary $k_{1\perp}v_{th}/\omega_c$ from 0.3 to 1.1. The growth rate decreases with $k_{1\perp}v_{th}/\omega_c$.

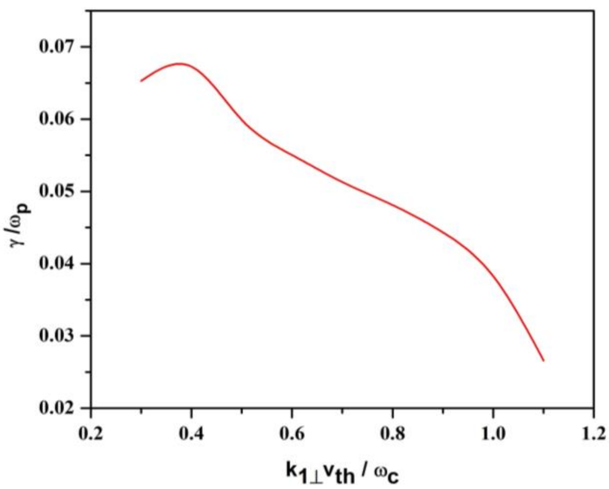

Figure 1: Variation of normalized growth rate γ/ω_p as a function of $k_{1\perp}v_{th}/\omega_c$ for the parameters $v_{th}/c = v_{1\perp}/c = 0.1,\ \omega_c/\omega_p = 0.2,\ l = 1.$

DISCUSSION

In a parametric decay instability, a large amplitude pump wave decays to two daughter waves once its amplitude exceeds a nonlinear threshold. Parametric decay instabilities occurring in connection with electron cyclotron resonance heating of plasmas are widely applied for ionospheric modification experiments as well as for generating and sustaining laboratory and industrial plasmas. Unlike X-mode waves, electron Bernstein waves can not be injected into a plasma from vacuum but are typically excited through linear conversion at the upper hybrid layer in O-X-B and X-B conversion schemes. Parametric decay instabilities in laboratory plasmas have been used to demonstrate the occurrence of O-X-B heating to provide direct heating and can also deliver information about the plasma parameters but have generally been ignored when computing electron cyclotron heating and current drive characteristics. The occurrence of parametric decay instabilities hamper and may damage laboratory electron cyclotron wave diagnostics. In ionospheric heating experiments, electromagnetic waves launched from the ground can give rise to density striation and excite waves that are trapped inside them. Because there is little convection out of the trapping region, the trapped waves may become unstable to cascades of parametric decay instabilities, which produce new waves escaping back to earth where they observed in rich frequency spectra. In inertial confinement fusion, the high power lasers used to compress fuel pellets may become unstable to a parametric decay instability known as a two Plasmon decay instability near the quarter critical surface where half the laser pump frequency corresponds to the plasma frequency. Since the wave excited by parametric decay instabilities under consideration are electrostatic in nature, hence they can not be detected directly by the steerable radiometer used in experiment. More specifically, the waves must somehow give rise to O-mode waves propagating toward the detector, owing to the cutoff region of the X-mode radiation and the settings of the steerable radiometer polarizers.

For typical parameters $v_{th}/c = v_{1\perp}/c = 0.1,$ $\omega_c/\omega_p = 0.2,\ l = 1,$ the growth rate is maximum when $k_{1\perp}v_{th}/\omega_c = 0.4.$ The maximum value of the normalized growth rate is 0.068. Upper-hybrid waves are observed in a variety of configurations, including beam-plasma systems, tokamaks, stellarators and space plasmas. In the absence of static magnetic field, a laser undergoes stimulated Raman scattering, stimulated Brillouin scattering, stimulated Compton scattering, two Plasmon decay instability, parametric decay instability, oscillating two –stream instability, filamentation instability and modulational instability.

ACKNOWLEDGEMENT

The authors express his gratitude to the Principal and Department of Physics, K.N. Govt. P.G. College, Gyanpur, Sant Ravidas Nagar, Bhadohi, U.P., India, for their insightful discussions and constructive suggestions.

REFERENCES

Agapitov O.V., Krasnoselskikh V., Mozer F.S., Artemyev A.V. and Volokitin A.S., 2015. Generation of nonlinear electric field bursts in the outer radiation belt through the parametric decay of whistler waves. Geophys. Res. Lett., **42**: 3715.

Arefiev A.V., Dodin I.Y., Kohn A., Du Toit E.J., Holzhatter E., Shevchenko V.F. and Vann R.G.L., 2017. Kinetic simulations of X-B and O-X-B mode conversion and its deterioration at high input power. e-print, arXiv:1612.07860.

Bjorn Grandal, 1976. Parametric decay instabilities in an infinite, homogeneous, weakly anisotropic plasma. Phys. Rev. A, **14**: 457.

Baek S.G., Parker R.R., Shiraiwa S., Wallace G.M., Bonoli P.T., Brunner D., Faust I.C., Hubbard A.E., LaBombard B. and Porkolab M., Measurements of ion cyclotron parametric decay of lower hybrid waves at the high-field side of Alcator C-Mod 2013. Plasma Fusion Control. Fusion, **55**: 052001.

Bulyginsky D.G., Gusev V.K., Djachenko V.V., Larionov M.M., Levin L.S., Serebreny G.A. and Shustova N.V., 1984. ECR-heating of plasma in FT-1 tokamak and its influence on the ion component, Proc. 11th European Conf. Controlled Fusion and Plasma Physics, **1**(Achen) (Mulhouse: European Physical Society), pg. 457.

Dorfman S. and Carter T.A., 2016. Observation of an Alfvén Wave Parametric Instability in a Laboratory Plasma. Phys. Rev. Lett., **116**: 195002.

Drake J.F., Kaw P.K., Lee Y.C., Schmidt G., Liu C.S. and Marshall N. Rosenbluth, 1974. Parametric instabilities of electromagnetic waves in plasmas Phys. Fluids, **17**: 778.

Dodin Y. and Arefiev A.V., 2017. Parametric decay of plasma waves near the upper-hybrid resonance. Phys. Plasmas, **24**: 032119.

Dermott F.S., Bekefi G., Hackett K.E., Levine J.S. and Porkolab M., 1982. Observation of the parametric decay instability during electron cyclotron resonance heating on the Versator II tokamak. Phys. Fluids, **25**: 1488.

Fujiyama H., Watanabe Y. and Akazaki M., 1980. Effects of the Collisional Damping on a Nonresonant Parametric Instability near the Lower-Hybrid Frequency. J. of the Physical Society of Japan, **49**: 1981.

Gusakov E.Z. and Popov A.Y., 2010. Low Threshold Parametric Decay Backscattering Instability in Tokamak Electron Cyclotron Resonance Heating Experiments. Phys. Rev. Lett., **105**: 115003.

Hussein A.A. and Scales W.A., 1997. Simulation studies of parametric decay processes associated with ionospheric stimulated radiation. Radio Science, **32**: 2099.

Hooke W.M. and Bernabei S., 1972. Observation of a Parametric Instability near the Lower Hybrid-Resonance Frequency. Phys. Rev. Lett., **29**: 1218.

Hiroe S. and Ikegami H., 1967. Excitation of Lower Hybrid Oscillations at Upper Hybrid Resonance by Microwaves. Phys. Rev. Lett., **19**: 1414.

Konar S. and Rai V., 1994. Parametric decay instability of an upper-hybrid wave in a two-temperature plasma. J. Plasma Phys., **51**, 193-200.

Laqua H.P., Erckmann V., Hartful H.J. and Laqua H., 1997. W7-AS Team and ECRH Group, Phys. Rev. Lett., **78**: 3467.

Laqua H.P., 2007. Electron Bernstein wave heating and diagnostic. Plasma Phys. Control. Fusion, **49**: R1.

Liu C.S. and Tripathi V.K., 1986. Parametric instabilities in a magnetized plasma. Phys. Rep., **130**: 143.

Okabayashi M., Chen K. and Porkolab M., 1973. Experimental Investigation of Plasma Heating by a High-Frequency Electric Field near the Electron Cyclotron Resonance in the FM-1 Spherator. Phys. Rev. Lett., **31**: 1113.

Ott E., Hui B. and Chu K.R., 1980. Theory of Electron Cyclotron Resonance Heating of Tokamak Plasmas. Phys. Fluids, **23**: 1031.

Parashar J., Pandey H.D. and Tripathi V.K., 1996. Laser–Bernstein-mode coupling in a laser-produced plasma Phys. Rev. E, **53**: 2735.

Pesme D., Laval G. and Pellat R., 1973. Parametric Instabilities in Bounded Plasmas. Phys. Rev. Lett., **31**: 203.

Porkolab M., 1974. Theory of parametric instability near the lower-hybrid frequency. Phys. Fluids, **17**: 1432-1442.

Porkolab M., 1982. Parametric decay instabilities in ECR heated Plasmas, Proc. 2nd Workshop Hot Electron Ring Physics (San Diego) ed N A Uckan (Alexandria: National Technical Information Service), **1**, 237.

Pietrzyk Z.A., Pochelon A., Behn R., Bondeson A., Dutch M., Goodman T.P., Tran M.Q. and Whaley D.R., 1993. Electron cyclotron resonance heating on the TCA tokamak. Nucl. Fusion, **33**: 197.

Saleem H. and Murtaza G., 1986. Nonlinear excitation of electron-acoustic waves. J. Plasma Phys., **36**: 295.

Wilhelm R., Erkmann V., Janzen G., Kasparek W., Muller G., Rauchle E., Schuller P.G., Schworer K. and Thumm M., 1994. The VII-A Team, Plasma Phys. Control. Fusion, **26**: 1433.