RL 83 029

WAVE GENERATION IN THE AURORA

R Bingham, D A Bryant, D S Hall

RUTHERFORD APPLETON LABORATORY
Chilton, Didcot
Oxfordshire
OX11 0QX

ABSTRACT

Wave generation mechanisms by a number of free energy sources in the magnetosphere are discussed. These include the temperature difference between the plasma sheet and the tail lobes, the temperature anisotropy, and field aligned currents. It is shown that a number of wave-modes can be generated via a Weibel-type instability by the above free energy sources, also the production of Langmuir waves can be created by ion-acoustic turbulence. Various wave-particle interaction mechanisms are presented as possible processes for the production of high energy electrons which are responsible for the aurora.

INTRODUCTION

Observational evidence of auroral electron and ion energy distributions with peaks in the range 1-20 keV suggest that the mechanism which accelerates the particles is a velocity dependent statistical process (Hall and Bryant (1974), Bryant et. al. (1978) and Bryant (1983)) and cannot be explained by a potential difference model. The need to consider an alternative to the potential difference model to account for the electron and ion distributions observed in the aurora and magnetosphere have been reported by Bryant et al (1978), Whalen and Daly (1979), Sharp et al (1980) and Birn et al (1981). The acceleration of auroral electrons by waves has been discussed in a companion report (Hall (1983)). In this paper we will consider the various free energy sources in the magnetosphere which could lead to the generation of plasma waves.

EXCITATION OF PLASMA TURBULENCE

There are a number of free energy sources in the magnetosphere which can excite plasma turbulence on auroral field lines. All the free energy sources ultimately derive their power from the solar wind. One way for the energy in the solar wind to be transferred to the magnetosphere is via magnetic-field-line reconnection (Galeev (1982)). The interaction between the solar wind and the magnetosphere compresses the plasma sheet transversely. The tail narrows leading to the tearing instability and the formation of a reconnection point. This in turn leads to enhanced particle flows and particle precipitation (Frank et al (1976), Hones et al (1972)).

As the plasma sheet is compressed the magnetic field B is enhanced and therefore the perpendicular temperature $T_\perp$ is also enhanced because $T_\perp/B$ is an adiabatic invariant. The field aligned adiabatic invariant causes the parallel temperature $T_{\parallel}$ to decrease as the plasma sheet is extended along the field lines. These two effects result in an increase in the temperature anisotropy $T_\perp/T_{\parallel}$. At the same time plasma inhomogeneities are enhanced on the boundary between the plasma sheet and tail lobe leading to steeper temperature and density gradients. The field aligned current $J_{\parallel}$ also increases as a consequence of magnetic field line reconnection.

The above free energy sources can power a number of plasma instabilities, however, we are only interested in those instabilities which lead to the excitation of plasma waves in well-defined frequency regions. When the temperatures are anisotropic in a magnetic field, plasma turbulence can be excited by a Weibel (1959) type instability with frequencies $\omega < \omega_{ce} (1 - T_{\parallel} /T_{\perp})$ and a growth rate $\gamma \alpha (T_{\perp} - T_{\parallel})T_{\perp}$. In particular if the anisotropy is in the electron temperature, whistler mode turbulence is generated, and if the anisotropy is in the ion temperature, Alfven mode turbulence is generated. In the presence of an electron temperature gradient Alfven waves can be generated by a drift instability (Coroniti and Kennel (1979)).

In the presence of the field-aligned currents the electron-ion drift instability generates ion-acoustic turbulence, this occurs when all electrons in the plasma have a velocity along a preferred direction with respect to the ions. This instability is analogous to a beam-plasma instability. So far we have considered only the generation of low frequency, low-phase-velocity waves which will be very effective in accelerating ions but not the electrons. Lin et al (1973) and Tsytovich et al (1975) have demonstrated that it is possible to generate high-phase-velocity Langmuir waves from ion acoustic turbulence. In Lin's theory ion wave fluctuations of wave number k_i and frequency ω_i are strongly coupled to high phase velocity Langmuir waves of wave number k_ℓ and frequency ω_ℓ and a longitudinal beat disturbance of wave number $k_\ell \pm k_i$ and frequency $\omega \approx \omega_\ell \pm \omega_i \approx \omega_\ell$. If the electrons are drifting with respect to the ions it is possible for the phase velocity of the beat disturbance to be such that the wave resonates with electrons that have a + ve slope in the distribution function, the beat-wave therefore absorbs energy from the electrons. The net effect is that the Langmuir waves at (k_ℓ, ω_ℓ) sees a negative resistance and is amplified. The effect is the inverse of non-linear Landau damping.

There will be significant growth of high phase velocity Langmuir waves from ion-acoustic turbulence if the growth rate given by (Lin et al (1973)) :-

$$\gamma = \frac{1}{8}\left(\frac{\delta n_i}{n_o}\right)^2 \frac{\omega_{pe}{}^4}{\omega_\ell} \quad \frac{\gamma_D \Delta}{[(\omega_\ell - \omega_i)^2 - \Delta^2]^2 + \gamma_D{}^2 \, \Delta^2}$$

where $\frac{\delta n_i}{n_o}$ is the level of ion wave turbulence,

$$\Delta = \omega_\ell - k_i v_d , \; \gamma_D = 2\pi \frac{\omega_{pe}{}^2}{|k_i|} v \frac{df_o}{dv} \bigg|_{v = v_d + \omega_\ell | k_i}$$

and v_d is the relative drift between electrons and ions, exceeds the Landau damping rate for these waves. These waves saturate by decaying to a white noise spectrum where their energy is absorbed with high efficiency, the energy going into accelerating electrons.

Other methods of accelerating electrons by other wave modes such as the whistler mode and Alfven mode have been considered. These include the ponderomotive force mechanism for the whistler mode, and the ponderomotive and the electromotive force for the Alfven waves (Namikawa et al (1982)).

Kinetic Afven waves, produced by resonant mode conversion of MHD surface waves, can also accelerate electrons by particle trapping or bounce resonance acceleration (Hasegawa (1976)). Another important wave mode which has a high-phase-velocity parallel to the magnetic field is the lower hybrid wave. This wave mode has been shown by Liu (1982) to be extremely effective in accelerating electrons parallel to the magnetic field.

CONCLUSIONS

Various free energy sources have been identified and shown to lead to a number of different wave modes which could be responsible for particle acceleration as seen in aurora.

REFERENCES

Birn J, Forbes T G, Hones E W and Bame S J

On the velocity distribution of ion jets during substorm recovery,
J. Geophys. Res., 86, 9001, 1981

Bryant D A, Hall D S and Lepine D R

Electron acceleration in an array of auroral arcs
Planet. Sp. Sci. 26, 81, 1978

Bryant D A

Acceleration mechanisms for auroral particles the observations, their current interpretation and need for a new approach. Rutherford Appleton report RL83 027, 1983

Coroniti F V and Kennel C F

Auroral micropulsation instability
J. Geophys. Res., 75, 1863, 1970

Frank L A, Ackerson K L and Lepping R P

On hot tenuous plasmas, fireballs and boundary layers in the earth's magnetotail
J. Geophys. Res., 81, 5859, 1976

Galeev A A

Magnetospheric tail dynamics, in "Magnetospheric plasma physics"
p 143, ed. by A Nishida, D Reidel Publishing Company, 1982

Hall D S and Bryant D A

Collimation of auroral particles by time-varying acceleration,
Nature, 251, 402, 1974

Hall D S

Acceleration of Auroral electrons by waves
Rutherford Appleton report RL83 028, 1983

Hasegawa A

Particle acceleration by MHD surface wave and formation of aurora
J. Geo. Phys. Res., 81, 5083, 1976

Hones E W, Asbridge Jr J R, Bame S J, Montgomery M D, Singer S and Akasofu S I

Measurements of magnetotail plasma flow made with Vela 4B
J. Geophys. Res., 77 5503, 1972

Lin A T, Kaw P K and Dawson J M

A possible plasma laser
Phys. Rev., A, 8, 2618, 1973

Liu C S, Chan V S, Chadra D K and Harvey R W

Theory of runaway-current sustainment by lower-hybrid waves
Phys. Rev. Lett., 48, 1479, 1982

Namikawa T and Hamalbata H

The mean electromotive force generated by random Alfven waves in a collisionless plasma
J. Plasma Physics, 27, 415, 1982

Sharp R D, Shelley, E G Johnson R G and Ghielmetti A G

Counterstreaming electron beams at altitudes of $\sim$ 1 Re over the auroral zone
J. Geophys. Res., 85, 92, 1980

Tsytovich V N, Stenflo L and Wilhelmson H

Current flow in ion-acoustic and Langmuir turbulence plasma interaction
Physica Scripta 11, 251, 1975

Weibel E S

Spontaneously growing transverse waves in a plasma due to an anisotropic velocity distribution
Phys. Rev. Lett., 2, 83, 1959

Whalen B A and Daly P W

Do field-aligned auroral particle distributions imply acceleration by quasi-static parallel electric fields?
J. Geophys. Res, 84, 4175, 1979