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EVOLUTION OF THE DRIFT WAVES IN THE UMIST LINEAR SYSTEM

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نمو الموجات المنحرفة في نظام اسطواني خطي ممغنط

ملخص درس هذا البحث الموجات المنحرفة في نظام أسطواني خطي، حيث اعتمدت الدراسة على استخدام مصدر لتوليد بلازما الهيدروجين في مجال مغناطيسي منتظم. ارتكز العمل التجريبي على قياس سلوك الموجات المنحرفة في مجال بلازما الهيدروجين الممغنط المنتظم ضعيف التأين وتأثير التصادم بين الأيونات والجسيمات المتعادلة مهمل. ولقد لوحظت الموجات المنحرفة ذات المدى الصغير لأرقام متعدد (موثلية) زاوية لشده مجالات مغناطيسية مختلفة. وجد أن تردد الموجات المنحرفة عموماً يزداد كلما ازداد شدة المجال المغناطيسي. لقد زودت النتائج اختباراً لنظرية النموذج الأسطواني غير الموضعي للأمواج المنحرفة في مجال البلازما الهيدروجين ذات التصادم المهمل في نظام أسطواني بشرط أن يكون نصف قطر لارمر كبير.

ABSTRACT **The system is based on the use of the duoplasmatron source to generate hydrogen plasma in a uniform magnetic field generated by a solenoid. The experimental work is based on the measurement of drift wave mode in a weakly ionized, collisionless hydrogen plasma in an axial magnetic field. The drift waves have been observed with a small range of a zimuthal mode number for various magnetic field strengths. The drift wave frequencies are generally found to increase with the magnetic field. The results will provide a test of the non-local theory of drift-waves in cylindrical geometry of collisionless plasma regime, in conditions in which the ion Larmor radius is large.**

I- INTRODUCTION

Many fundamental experiments in plasma instabilities have been performed using Q-machine which is limited to the use of high-mass ions (alkali metal), (Motley 1975). This machine produces cold (<lev) and heavy (m_i>>1 a,m.u) ions with a wide range of densities. Producing a quiescent,

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steady state, gaseous hydrogen plasma embedded in an axial magnetic field is therefore of interest in plasma research. **The UMIST*** Linear System has been built and operated, and drift waves have been observed. This device is a vacuum vessel aligned along the axis of the magnetic coils, and made of stainless-steel material. At one end of the device, the hydrogen plasma is generated externally from a duoplasmatron source and confined in a cylindrical geometry at low magnetic field ≤ 1.2 Kgauss. Detailed description of the device can be found in Yassin(1991). Drift waves have been frequently observed and studied over the past years (Van Andel etal 1979 and Ellis etal 1980). This instability has been investigated in many devices, both linear and toroidal and in both the collisonal and collisionless dominated plasma regimes; to our knowledge, the majority of detailed work has been performed on collisional plasma regime, whilst the collisionless plasma regime has received less attention. The experiments reported throughout this paper are based on the observation of drift waves in a weakly ionized, collisionaless hydrogen plasma in an axial magnetic field.

II- Experimental details

II- 1 The Linear System

The magnetic field, of up to 1200 Gauss, is generated by a set of eight pancake coils energized by a smoothed transformer-rectifier power supply delivering up to 1000A at 40V. The solenoid is 1 m long; the vacuum vessel is 0.15m diameter by 2m long and has observation ports at the centre and far end, and the plasma source is located on the central axis 0.55m from the end coil. The plasma in the solenoid consists of a hot core ($T_e \approx$ 5-10 ev) of radius 5-10mm surrounded by an extensive cooler region ($T_e \approx$ 1 ev) extending out to at least 3cm; the plasma density is quite well described by

$$\frac{n}{n_0} = \frac{1}{1 + \frac{r^2}{a^2}}$$

With a = 6.3mm in a typical case and n_o is the plasma density at the plasma beam center. However, the distinction between “hot” and “cold” plasma is less marked than in the quadrupole (Phillips et al. 1978.)

In the quadrupole (Phillips et al 1978), it is known to be important to provide an earthed surface near the duoplasmatron to collect the excess electron current produced by this source (up to 0.5-1 A may be collected); failure to do this disrupts the injection process. In the linear system, we believed that a similar electrode should be provided to drain the electron current from the plasma beam, which might otherwise produce an excessive electron drift velocity in the plasma. Accordingly, a grid of mesh size 0.40 mm was placed across the plasma beam 0.2m from the source; up to 450 mA may be drawn from it. The main effect of this is to reduce the core density with respect to the outer region of the plasma; at the same time the core temperature increases. This temperature is mainly controlled by the gas throughput in the source, but at any gas throughput the temperature increases by 50% as the grid current is increased from 0 to 350 mA. The grid has been kept in place for much of the work to provide a degree of control over the plasma.

The neutral pressure in the system is typically in the range (2-10) X 10^{-5} torr, giving electron mean free paths in the range 3-15m; however, it should be noticed that a typical electron must be electrostatically confined at the machine ends and transverse the machine 50-100 times before being lost. Thus, collisions should not be neglected.

II- 2 Fluctuations

These have been observed using cylindrical Langmuir probes placed a few mm off axis at the centre of the solenoid, where the density gradient is maximum. A typical power spectrum (Figure 1) shows a continuous background with 1-4 narrow peaks superimposed; the background has a power low form with $P(f) \propto f^{-1.4}$ approximately. (The low-frequency cut-off is due to a filter, which used throughout the experiment). The peaks (which vary considerably in width) have frequencies in the range 50-250 kHz. The frequency, and level of excitation, of each peak is a function of magnetic field; Figure 2 shows a typical set of results. As can be seen, the range of field over which a given peak is excited varies widely. Typically, the relative amplitude n/n_o is of the order of 10%.

The m-numbers of these peaks have been determined by the use of probes at different azimuthal angles; the peaks in Figure 2 have m = 1,3 and 4 in order of increasing frequency. (It is not clear why m = 2 is not observed here; m = 2 peaks have been seen in other conditions, but this mode does seem to be less commonly excited than the others). The observed frequencies typically have ratios like 1:2.25:3.5; so they are not simply harmonics, nor is the frequency strictly proportional to the m-number.

The amplitude of these modes is zero on the axis and reaches a maximum just beyond the point of steepest density gradient, typically at 8mm from the axis. Further out the spectrum shows only the power law background.

III- Discussion and Results

III- A Plasma injection

The radius of the hot core is about equal to the ion Larmor radius and scales with magnetic field in the same way. This has suggested a model of the plasma injection which is certainly not complete, but will serve an initial standard of comparison.

The source is not placed right in the solenoid entrance but about 0.55m away from it in a region of steeply falling field strength; this was intended to allow the plasma beam from the source to spread out before reaching a field sufficient to magnetize the particles. As a result, the field seen by the source is essentially that of a spindle cusp, and the hot plasma core outlines the hole size of the cusp; it is of some interest that this is about the ion Larmor radius. Specifically, the source should be thought of as producing an electron could, but an ion beam as well, the ions being accelerated by the potential fall due to plasma expansion to an energy of the order of T_e. The ion beam expands to form a cone of half-angle θ_0, and becomes magnetized at a distance z_o in front of the source orifice traveling at θ to the axis satisfies

$$z_0 B(z_0) = 2mV\cos\theta / e$$

The guiding centre then lies at $r_o = z_o \tan\theta$

If (as usual) $B(z_o) \ll B_m$, the solenoid field, the injected ions may still be mirrored as they approach the solenoid and will then be lost. However, if the condition

$$\sin^2\theta_0 < \frac{B(z_0)}{B_m}$$

is satisfied, all the ions can inject. Unless the condition is satisfied by a large margin, the ion beam in the solenoid will have a maximum radius of twice the Larmor radius, while the density is a complex function of the ratio $B(z_o)/B_m$.

The results show that the half-width (radius at half-height) of the plasma density distribution may be equal to the ion Larmor radius, ρ_i. If the half-width of the density distribution taken to be 6 mm (see Figure 3), and the ions are assumed to be hydrogen, the ion energy would be 16 ev, which is quite possible for the hydrogen ion. This suggests that we have produced a plasma in which the ion larmor radius is large, comparable to, or equal to the plasma beam radius. However, the density is lower than would be expected, particularly at high magnetic field, suggesting that losses due to mirroring occur.

In any case, it seems likely that we have inadvertently produced a plasma in which the ion Larmor radius is large, comparable to, or equal to, the scale length of the central hot core. It remains to be seen whether a region of small Larmor radius is accessible in the outer parts of the plasma.

However, this model cannot account for the slow density fall-off outside the hot core; it would predict a more-or-less Gaussian fall-off, rather than the $(1+r^2/a^2)^{-1}$ form observed. Further, it demands that the electrons, magnetized much sooner than the ions, are nevertheless able to follow them. Both these points indicate that significant radial diffusion is occurring. Clearly, one possibility is that the reflected particles are interfacing with the walls of the vacuum vessel so as to return along field lines further from the axis. We propose that source optimization, combined with the use of a diaphragm to define the half-angle of the beam, will eliminate this possibility; then any remaining broadening of the distribution must be due to diffusion in the bulk of the plasma. (Indeed, diffusion, e.g due to drift waves, could be measured more clearly in this system than in the quadrupole where the possibility of radial drifts due to longitudinal electric fields can not be ruled out). Since the ions are expected to traverse the system once only, time dependence converts into a dependence on distance along the field from the injection point.

The most plausible explanation for the temperature rise when current is collected from the grid is that low energy electrons are preferentially absorbed. In a Maxwellian distribution f (E) at temperature T, if we extract all particles below energy E, and allow the remaining particles to thermalise, the temperature becomes

$$T^{1} = \left(1 + \frac{k}{3}\right)T$$

where

$$k = \frac{E_0\, f(E_0)}{\int_{E_0}^{\infty} f(E)\,dE}$$

However, the calculated electron-electron relaxation time is about 700 μsec while a typical electron lifetime is around 20-30 μsec, so this explanation does require an anomalously rapid thermalisation.

III- B Fluctuations

The narrow peaks of power spectrum shown in figure (1), may be identified as drift waves by their propagation in the electron drift direction and the fact that the diamagnetic drift frequency ω^* evaluated at the position of maximum wave amplitude, is of the right order of magnitude. For comparison with our results, we have used the non-local theory of Ellis and Marden-Marshall (1979), simplifying it by taking the collisionless limit. In this theory the ions are assumed cold and the electron temperature constant; we have used the electron temperature corresponding to the peak of the relative mode amplitude n/n_o, which occurs at about 10 mm radius at 750 Gauss field (Figure 3), giving T_e = 1.8 ev. The radial eigen-function determined from the theory is shown in Figure 4; the corresponding eigen-value gives a frequency of 69 kHz which agrees well with that observed (Figure 2). However, the predicted maximum amplitude occurs at about half the radius of the observed peak. Further, since the core distribution contracts as the field increases, the theory predicts that the frequency should increase linearly with magnetic field; experiment shows the frequency increasing but showing signs of saturation.

The observed drift wave frequency obtained in the present work is supported by another work; Egger et al (1986) and Kauschke et al. (1990). Their experiments were performed in a cylindrical geometry with an axial field of B< 1500 Gauss, but different plasma. At these low magnetic fields the mode frequencies are generally found to increase with the magnetic field and to obey the non-local theory Figure 2 also reproduces the comparision between the experimental data of Egger et al. And Kauschke et al., as well as the results obtained throughout this work.

We assume the mode to be collisionaless drift mode, for which an approximate instability criterion can be derived from Ellis and Marsden-Marshall (1979): in the absence of longitudinal drift, the condition is

$$\omega^2 > \frac{\upsilon_i}{\upsilon_e} k^2{}_{11} V_{\theta_e}{}^2$$

Where $\upsilon_{i,}$ υ_e are the ion and electron collision frequencies; assuming $k_{11} = \pi /L$ where L =1 m is the length of the solenoid, we find that this condition is satisfied only for

$$\omega/2\pi > 490 \text{ kHz}$$

So none of the modes shown in Figure (2) should be unstable. However, the condition is considerably relaxed when the plasma carries a current, and in the future we shall be examining the distribution of current in the plasma in detail so as to incorporate it into the model, which will also be modified to include a varying temperature, and later the effect of finite ion Larmor radius, as well as the E x B rotation into the theory.

For unstable modes the predicted growth rates satisfy $\gamma/\omega= 10^{-3}$ to 10^{-2}, in agreement with the very narrow peaks sometimes observed.

IV- Conclusions

The drift waves have been observed with a small range of azimuthal mode number for various magnetic field strengths. The experimental values of the mode frequency as a function of the magnetic field, and the radial fluctuation levels of the wave amplitude are presented. The observed frequency shows a marked increase with the magnetic field. A non-local cylindrical model is simplified to the collisionless magnetized plasma and compared to the experimental values. It is found that the theoretical eigen-mode of the wave amplitude maximizes at about half of the maximum position of the experiment. This suggests that, the inclusion of temperature gradients and the plasma rotation should be considered in the theory. Despite a small range of experiments were performed, the results will provide a framework for the performance of future experimental studies consisting of a larger, more extensive work of instabilities in a uniform magnetized plasma in a collissionless regime.

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