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that BEKEFI and HOOPER (1964), ROBERTS (1966), and others have reported observing cyclotron radiations from beam generated plasmas. These two investigators were mentioned because they observed similar phenomena dispite having quite different beam parameters; Bekefi had a very low power beam while Roberts used an electron gun from a high power klystron. In this phase of the experiment, the Rensselaer electron gun is fundamentally different from both of these in that while they both use cathodes that are shielded from the axial magnetic field, we have a cathode which due to the removal of magnetic shielding, is immersed in the field. The result is that they both have electron beams with significant transverse energy due to magnetic lens effects (MIHRAN, 1962). Thus we found that when the 'yoke' of soft iron was again used to partially shield our gun from the axial field, thereby forming a magnetic lens, electron cyclotron radiation did appear. The 'tuning' curve for this radiation is shown in Fig. 3b. Of course, it was found that the beam generated plasma had the expected wide band noise which was absent for beam-cesium plasma operation under similar conditions of plasma density, beam current, and energy.

In conclusion, these preliminary measurements indicate both the desirability and the feasibility of using such a cesium plasma system for the study of beam plasma interactions.

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REFERENCES

BEKEFI G. and HOOPER E. B. (1964) *Appl. Phys. Lett.* **4**, 135.
FREDRICKS R. W. (1968) *J. Plasma Phys.* **2**, 365.
GUNSHOR R. L. and MIHRAN T. G. (1968) *J. appl. Phys.* **39**, 4636.
MIHRAN T. G. (1962) *J. appl. Phys.* **33**, 1582.
ROBERTS M. (1966) Ph.D. Thesis, Cornell University.

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Rotation of a collisional Theta pinch plasma

THETA pinch plasmas have been observed to rotate rapidly, lose rotational symmetry and become turbulent. Recently, DÜCHS (1968) has investigated rotation using a two-dimensional computer model for a collisional plasma. He finds appreciable rotation if a transverse magnetic field exists across the plasma. In recent experiments on collisional plasma (BENFORD, 1969) rotation has been found. This raises the question of whether a previous mechanism due to VELIKHOV (1964) for collisionless plasmas may be present here as well.

VELIKHOV (1964) has treated the rotation of an axially symmetric theta pinch which arises from finite Larmor radius corrections to the ion diamagnetic currents. He considered the collisionless regime ($\Omega_+\tau \gg 1$, where Ω_+ is the cyclotron frequency and τ the momentum relaxation time for ion-ion collisions) and found that the plasma divided radially into oppositely rotating parts. This note derives this effect for arbitrary $\Omega_+\tau$.

Following Velikhov, we consider a plane layer of plasma uniform along the y-axis and moving along the x-axis, parallel to the imposed magnetic field B. (A description of this effect in cylindrical coordinates appears in a general review of theta pinch rotation by HAINES (1965).) The hydromagnetic equation of motion of the plasma is

$$m_+ n_+ \frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = -\vec{\Delta}P - \vec{\Delta} \cdot \overset{\Rightarrow}{\pi} + \frac{en}{c}\left(\vec{v}_+ - \vec{v}_-\right)x\vec{B} \qquad (1)$$

where $\overset{>}{v}$ is the hydrodynamic velocity and $+$ subscripts refer to ions and $-$ subscripts to electrons.
P is the scaler pressure and $\overset{>}{\overset{>}{\pi}}$ the stress tensor. For this problem there is no radial current, $v_{x+} = v_{x-}$, and the y component of equation (1) becomes

$$m_+ n_+\left(\frac{\partial}{\partial t} + v_x\frac{\partial}{\partial x}\right)v_y = -\left(\overset{>}{\Delta}P\right)_y - \left(\overset{>}{\Delta}\cdot\overset{>}{\overset{>}{\pi}}\right)_y = -\frac{\partial P}{\partial y} - \frac{\partial}{\partial x}\pi_{xy} - \frac{\partial}{\partial z}\pi_{zy} - \frac{\partial}{\partial y}\pi_{yy}. \quad (2)$$

An expression for $\overset{>}{\overset{>}{\pi}}$ for arbitrary $\Omega_+\tau$ has been given by KAUFMAN (1960). We assume

$$\frac{\partial P}{\partial y} = 0, \qquad \frac{\partial v_x}{\partial y} = 0, \qquad \frac{\partial v_y}{\partial y} = 0, \qquad v_z = 0 \quad (3)$$

and find the only contribution to equation (2) is from π_{xy},

$$\pi_{xy} = \frac{(\Omega_+\tau)^2}{1 + 4(\Omega_+\tau)^2}\frac{P}{\Omega_+}\frac{\partial v_x}{\partial x}. \quad (4)$$

We thus wish to find the conserved mechanical angular momentum for a fluid obeying the equation of motion,

$$m_+ n_+\left(\frac{\partial}{\partial t} + v_x\frac{\partial}{\partial x}\right)v_y = -\frac{\partial}{\partial x}\frac{(\Omega_+\tau)^2}{1 + 4(\Omega_+\tau)^2}\frac{P}{\Omega_+}\frac{\partial v_x}{\partial x}. \quad (5)$$

An elegant treatment of the Lagrangian method in magnetohydrodynamics by NEWCOMB (1962) enables us to write the Lagrangian for equation (1) in Eulerian variables, with $\overset{>}{\overset{>}{\pi}} = 0$, as

$$L = \frac{\rho}{2}v^2 - \frac{P}{\gamma - 1} - \frac{B^2}{2} \quad (6)$$

where quantities are as defined by HAINES (1965). We must find an additional term in the total Lagrangian,

$$L_t = L + Q \quad (7)$$

such that the Langrangian equation of motion is equation (5). The invariant momentum p_i for coordinate x_i will then be

$$p_i = \int \mathrm{d}^3x\,\frac{\partial L_t}{\partial \dot{x}_i}\,\delta x_i.$$

(Note that if $\overset{>}{\overset{>}{\pi}} = 0$, $p_y = nv_y$.)
  A form which satisfies equation (5) is (in Eulerian coordinates)

$$Q = +\frac{2(\Omega_+\tau)^2}{1 + 4(\Omega_+\tau)^2}\frac{P}{\Omega_+}\frac{\partial v_x}{\partial x}. \quad (8)$$

The invariant momentum is

$$p_y = nv_y - \frac{4(\Omega_+\tau)^2}{1 + 4(\Omega_+\tau)^2}\frac{\partial}{\partial x}\left(\frac{kT_+n_+}{2m_+\Omega_+}\right) \quad (9)$$

where we have assumed $(\Omega_+\tau)^2$ is a constant for the plasma. The calculation may be carried through in cylindrical polar coordinates to give

$$p_\theta = \rho r^2\dot{\theta} - \frac{4(\Omega_+\tau)^2}{1 + 4(\Omega_+\tau)^2}\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{n_+kT_+r^2}{2\Omega_+}\right). \quad (10)$$

This result differs from that of HAINES (1965) only in the factor

$$\frac{4(\Omega_+\tau)^2}{1 + 4(\Omega_+\tau)^2},$$

multiplying the ion diamagnetic term. It is this factor which describes the importance of finite ion

Larmor radius effects. The effective viscosity due to these effects allows angular momentum to be transported radially through the plasma. It is clear that for a collisional plasma the effect is much reduced. For the cases measured by BENFORD (1969), $(\Omega_+\tau) \cong 10^{-2}$ and the resulting rotation is negligible.

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REFERENCES

BENFORD J. N. (1969) *Physics Fluids* (In press).
DÜCHS D. (1968) *Physics Fluids* **9**, 2010.
HAINES M. G. (1965) *Adv. Phys.* **14**, 164.
KAUFMAN A. N. (1960) *Physics Fluids* **3**, 610.
NEWCOMB W. A. (1962) *Nucl. Fusion Suppl.* **2**, 451.
VELIKHOV E. P. (1964) *Plasma Phys.* (*J. nucl. Energy*, Part C) **6**, 203.

A thermionic lithium plasma source for drift wave experiments

1. INTRODUCTION

WE ARE building an experiment to investigate drift waves in a cylindrical column of plasma produced by the thermal ionisation of lithium atoms at a hot metal surface. Considerations of power consumption in the field windings limit the column radius R and we are therefore working with a lithium plasma in order to make the ion Larmor radius a_i small. In this way we avoid the ion-cyclotron instability, which MIKHAILOVSKII (1965) predicts will disappear if $R/a_i > (m_i/m_e)^{1/2}$; m_i and m_e being the ion and electron masses respectively.

   In collision dominated plasmas, for which thermal equilibrium between plasma and hot plate can be assumed, the plasma density is predicted to be independent of the value of ϕ_i, suggesting that any refractory metal surface could be used to produce a lithium plasma (VON GOELER, 1964). However, low density plasmas may not be in thermal equilibrium and it is desirable to use rhenium hot plates in order to optimise the ionisation of lithium (ZANDBERG and TONTEGODE, 1965). We have produced lithium plasmas by ionisation at tantalum, tungsten and rhenium surfaces and have confirmed qualitatively ionisation rates calculated from their data.

   It is well known that temperature gradients across the hot plate affect the plasma seriously (ENRIQUES *et al.*, 1968). Azimuthal temperature variations must be less than $\pm 5°K$ to make the radial drift of the plasma negligible (BURT *et al.*, 1969). The isotherms must be closed, and ideally should be concentric circles.

2. PLASMA SOURCE DESIGN

   In this source the hot plate (Fig. 1) consists of a rhenium disc, of dia. 6 cm and thickness 1·5 mm supported in one end of an 8 cm long tantalum cylinder. The rhenium is backed by a tungsten disc of similar dimensions. The plates are separated by 0·5 mm and the facing surfaces have been roughened by spark erosion to improve the radiative heat transfer. Temperature distributions for a variety of designs have been computed (BURT *et al.*, 1969).

   In order that the plasma potential may be varied, the hotplate is insulated from Earth at the cold end of the tantalum support tube by insulators of boron nitride. Having a vapour pressure of 10^{-4} Torr at 1750°C this material is unfortunately unsuitable for insulation purposes within the hotplate itself.

   It is calculated that 2–3 kW are lost by radiation from the hotplate. Conduction losses are reduced