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Report

A MASS ANALYSER FOR USE IN MAGNETICALLY CONFINED PLASMA STREAMS

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by

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ABSTRACT

This note describes a time-of-flight analyser designed to measure the charge/mass ratio of the ions of a plasma streaming in a uniform parallel magnetic field. The analyser has been tested in plasmas of number density 10^{10}-10^{11} cm^{-3}, in which the ions have thermal and streaming energies of about 50 eV.

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1. INTRODUCTION

In studies of a plasma confined in a magnetic field, one often wishes to determine the charge/mass ratio of the different ions confined in the plasma. Most conventional mass spectrometers do not work when immersed in a magnetic field; use of a mass spectrometer positioned outside the magnetic field would entail the risk that not all ion species leave the magnetic field in the same proportion. The present analyser overcomes this problem, and functions satisfactorily when its axis is aligned parallel to a uniform magnetic field.

2. DESCRIPTION OF ANALYSER

Simonov and Mileshkin (1962) describe an instrument which is, in some part, similar to the one described in this note. The basic principles of operation of time of flight analysers are discussed by Harrington (1960). Our analyser is shown in Fig.1, and is aligned parallel to the magnetic field.

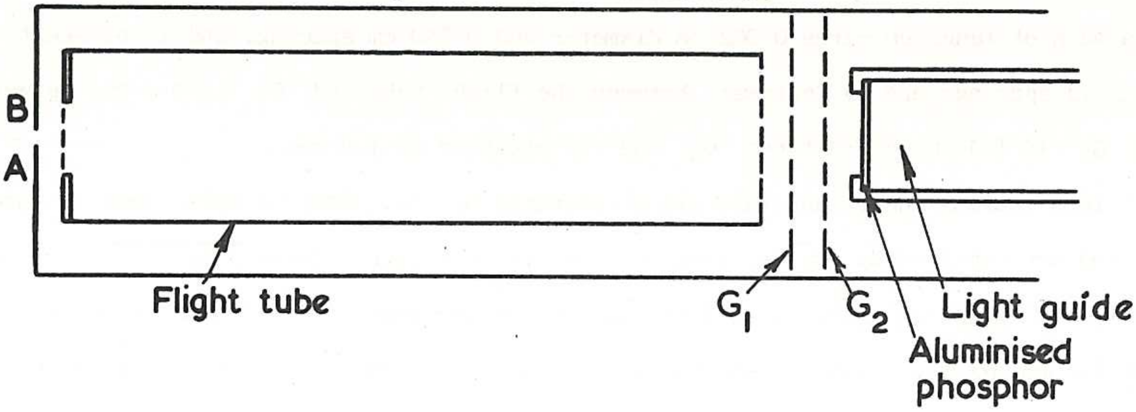

Fig.1 Diagram of Analyser
(Not to scale)

The instrument consists of an earthed stainless steel outer casing A, of diameter 7·6 cm, with a 0·0025 cm. hole B in its front face. The diameter of this hole is less than one Debye length. A stainless steel flight tube of length ℓ = 36·2 cm and diameter 5 cm is positioned behind the hole. On the front face of the flight tube is attached a square-mesh grid of tungsten wire, of diameter 0·001 cm and spacing 0·005 cm. Several different distances between this grid and the pinhole have been tried; the performance of the analyser was found to be unaltered when this distance was varied between 0·2 and 1·2 cm. The back face of the flight tube is a square-mesh grid of tungsten wires of diamter 0·002 cm and spacing 0·050 cm.

The flight tube is biased to a positive voltage V_F, sufficient to repel all incident ions. The instrument is gated by a rectangular pulse, of duration τ and height $-V_G$, applied to the flight tube. Ions of atomic weight A and charge Ze have a time of flight down the tube given by

$$t = \ell \left[\frac{M_p A}{2Ze \; (V_i \pm \Delta V_i + V_G - V_F)} \right]^{\frac{1}{2}} \qquad \ldots (1)$$

where the incident ions have an energy spread $(V_i \pm \Delta V_i)$ eV along the magnetic field. Ions of different mass/charge ratio therefore arrive at the detector at different times, and can be recognised accordingly.

The detector is a scintillator-photomultiplier arrangement of the type described by Mason (1964) and Osher (1965). The detector consists of a secondary emission grid G_1, an ion repeller grid G_2, an aluminised phosphor and a light guide leading to a screened photomultiplier. The grid G_1 is a 50% transparent copper mesh biased to − 8 kV. Grid G_2 is a mesh of tungsten wires 0·002 cm diameter and 0·050 cm spacing, and is biased to + 2 kV. The grid spacings are as follows: between the flight tube and G_1 is 1·6 cm, between G_1 and G_2 is 1·4 cm, and between G_2 and the phosphor is 1·9 cm.

Ions leaving the flight tube are accelerated by G_1. Some of these ions go through G_1 and are repelled by G_2, hitting G_1 on its back face. These ions release secondary electrons, which are accelerated past G_2 to the phosphor. The aluminisation on the phosphor is approximately 2,000 Å thick. This is just thin enough to allow penetration by the accelerated secondary electrons to the phosphor, but thick enough to prevent light from the plasma reaching the photomultiplier.

A dual beam oscilloscope records:

(i) The gate signal V_G

(ii) The photomultiplier signal (via an amplifier).

From the oscilloscope records, it is possible to determine the time of flight of the different ion species.

3. RESOLUTION OF THE INSTRUMENT

The width of any peak recorded by the photomultiplier will depend upon ΔV_i , τ and ΔV_G. (It is not possible to produce an accurately rectangular gate pulse if the duration τ is short. The actual amplitude of the pulse will vary between $(V_G + \Delta V_G)$ and $(V_G - \Delta V_G)$, due to overswing.)

For resolution between singly charged ions of atomic weights A and (A + 1), the following approximate criterion is necessary:

$$\tau + \frac{A^{\frac{1}{2}} t_p (\Delta V_i + \Delta V_G)}{(V_i + V_G - V_F)} < t_p \left[(A+1)^{\frac{1}{2}} - A^{\frac{1}{2}} \right] , \qquad \ldots (2)$$

where t_p is the time of flight of a proton through the flight tube.

Eq.(2) indicates that resolution between adjacent species becomes more difficult as A increases. For best resolution, τ must be small, the quality $V_G/\Delta V_G$ of the gate pulse must be high, and $(V_i + V_G - V_F) \gg (\Delta V_i + \Delta V_G)$ should be made to hold.

4. RESULTS OBTAINED WITH THE ANALYSER

The analyser was tested in the plasma produced by the quasi-steady-state accelerator described by Ashby (1968). An oscilloscope trace is shown in Fig.2. This trace was obtained for a deuterium-fed accelerator, with $V_G = -1{\cdot}5$ kV and $V_F = + 320$ V. The first peak corresponds to H^+, probably from water vapour in the vacuum system. The second peak corresponds to D^+. The double structure of each peak results from the shape of the gating pulse which was not exactly rectangular. When hydrogen was used instead of deuterium, the second peak disappeared. With helium the first peak corresponding to H^+ was still present, while the helium peak was usually fairly weak, though still observable.

Fig.3 plots $1/t^2$ against $(V_G - V_F)$ for the H^+, D^+ and He^+ signals. If accurate resolution between adjacent species is required, it is essential to obtain A/Z from the slope of such a graph, and not from a single measured point, since the straight line graph does not go through the origin. The time t must be corrected from the delay introduced by the amplifier between the photomultiplier and the oscilloscope. The time t is measured from the instant that the gate pulse first reaches its maximum value, to the start of a peak recorded by the photomultiplier.

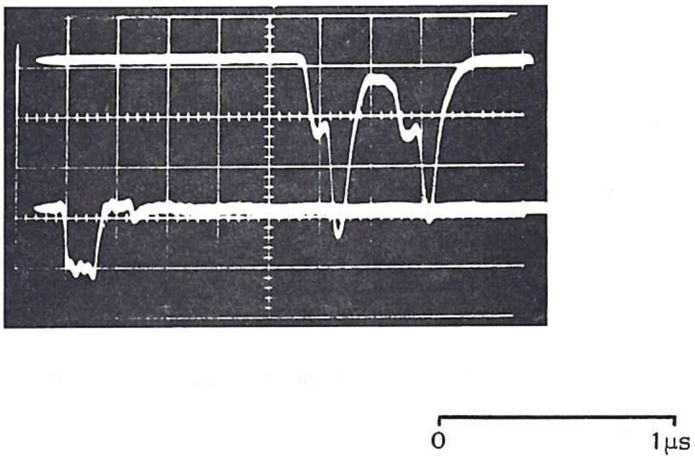

Fig.2 Upper beam: photomultiplier signal
Lower beam: gate signal.

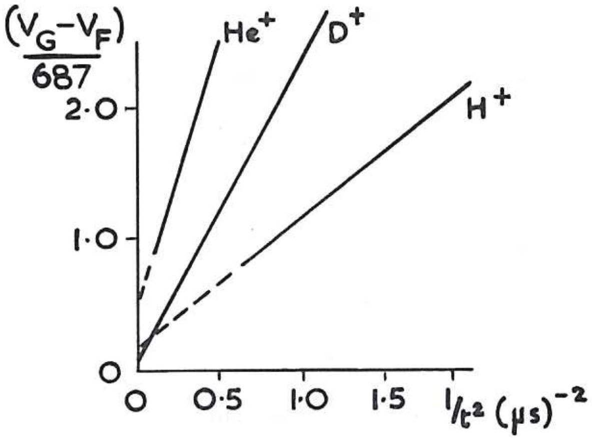

Fig.3 Plot of $(V_G - V_F)$ against $1/t^2$, for a flight tube of length 36·2 cm.

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5. ESTIMATION OF PERCENTAGE OF IMPURITY PRODUCED BY QUASI-STEADY-STATE ACCELERATOR

The time of flight analyser was used to obtain a rough estimate of the percentage impurity produced by the quasi-steady-state accelerator of Ashby (ibid). This impurity was composed mainly of atomic mass 12 to 16, and from the ratio of photomultiplier signals corresponded to roughly 10%.

A quantitative measurement of the impurity depends upon a knowledge of the secondary emission coefficients of copper, when bombarded by 8 keV ions of the different constituent ion species. As these coefficients depend upon a number of factors (e.g. the amount of gas occluded onto the copper), no more than an estimate of the percentage impurity can be obtained, unless the instrument is calibrated against a known source of ions; this drawback is common to the majority of analysers.

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