INSTITUTE OF PLASMA PHYSICS

NAGOYA UNIVERSITY

RESEARCH REPORT

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ION DRIFT VELOCITY MEASUREMENT IN A COLLISIONAL PLASMA

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ABSTRACT

In a rotating plasma, immersed in crossed electric and magnetic fields, plasma rotation velocity is obtained by determining radial electric field E_r by Langmuir probe, including finite Larmor radius effect, and by test wave technique. A disagreement between the two velocities is found. This disagreement is not removed even if the collisional effects are included in the velocity determined by E_r. This difference is attributed to the inappropriate collision cross section. It is suggested that at low energies instead of total collision cross section, the so-called "slowing down" cross section should be used, and at the same time, cylindrical effects must be taken into account.

INTRODUCTION

It is well known that a plasma, immersed in perpendicular electric and magnetic fields, drifts with a velocity $V = \frac{c\vec{E}_r \times \vec{B}}{B^2}$. During the investigations of plasma instabilities, we should determine the plasma rotation accurately, duly considering the Doppler effect. For this purpose, in low temperature plasmas, E_r is determined by Langmuir probe, which is ambiguous and vulnerable to many errors. Particularly at low magnetic field where ion Larmor radius is large and/or high pressure where collisions are dominant, corrections of finite Larmor radius and/or collision effect are necessary. Therefore, for cross check, some other method should be searched out.

For this purpose test wave method appears to be a powerful and reliable diagnostic tool. Wong and Jassby1) have used it in a collisionless plasma where ion cyclotron frequency is much greater than the instability frequency and Hsuan et al.2) have used it to determine the flow velocity of plasma into the divertor of the FM-1 spherator. In this report we present the results of our investigations in a collisional plasma immersed in a low magnetic field where ion Larmor radius is large. Plasma rotation velocity is determined by two methods, test wave technique and Langmuir probe, applying the Larmor radius correction, and the discrepancy between the two leads to a more appropriate collision cross section which should be used in the analysis of ion motion in a collisional plasma.

EXPERIMENTS

The experiment is performed in Penning discharge. The stainless steel discharge tube is about 160 cm long and 12.5 cm in radius with an annular ring anode at the center as shown in Fig.1. Indirectly heated oxide coated cathode 6 cm in diameter is used for the plasma production. Measuring ports are located nearly at the center of the discharge tube, separated azimuthally through 90° intervals through which exciter and receiver are introduced to the plasma.

The experiment is conducted in low magnetic field and high pressure regime, $1.0 \sim 6.0 \times 10^{-3}$ Torr in argon. The plamsa radius is 6 cm, $n \simeq 10^{10}$ cm^{-3}, T_e is $1 \sim 3$ eV and ion plasma frequency is 3.3 MHz. The discharge voltage V_d is $40 \sim 70$ volts and discharge current is varied from 100 to 700 mA.

WAVE EXCITATION

The wave is excited by a single tungsten wire 0.5 mm in diameter and 3 cm in length and received by a wire of same dimensions biased negatively with respect to plasma. Both the exciter and receiver, which are aligned parallel to the magnetic field (Fig.2), are movable radially and one of them is also movable azimuthally so that the wave can be excited at any desired position or in any direction, clockwise or anticlockwise. To study the wave propagating azimuthally, the azimuthal spacing between exciter and receiver is kept sufficiently small as compared with their radial distance from the plasma axis. The transmitted and received signals are fed to an interferometer whose output, as a function of frequency, is displayed on CRO. When the wave is travelling in the direction of plasma rotation, its phase velocity is given by $(C_s - V_d)$ while in the opposite direction is given by $(C_s + V_d)$. If the signals of exciter and receiver can be represented by

$$f(t) = A\, e^{i\omega t}$$

and

$$g(t) = B\, e^{i(\omega t - kx)}$$

the output of the interferometer is given by

$$I = \frac{1}{T}\int_0^T ABe^{i\omega t}\, e^{-i(\omega t - kx)}dt$$

$$= ABe^{ikx}$$

$$R_e I = \cos kx$$

and

$$kx = \frac{\omega x}{C_s \pm V_d} \qquad (1)$$

where "x" is the separation between exciter and receiver and V_d is the drift velocity given by$^{3)}$ (provided that cartesian geometry is, locally, very much similar to the cylindrical geometry)

$$V_d = \frac{(\Omega_{ci}\tau_i)^2}{1 + (\Omega_{ci}\tau_i)^2}\left(- \frac{cE_r}{B} + \frac{\kappa k T_i}{eB}\right) \qquad (2)$$

where $\kappa = \frac{1}{n}(dn/dx)$, Ω_{ci} is the ion cyclotron frequency and

τ_i is the ion-neutral collision time. For one set this separation "x" is kept constant and frequency "ω" is swept from 100 kHz to 5 MHz. By launching waves in the direction of plasma rotation and in the opposite direction, two wave patterns are obtained. From the two consecutive peaks of the output patterns, as shown in Fig.3, the frequency difference $\Delta\omega$ given by $\frac{\Delta\omega}{2\pi}\, x = C_s \pm V_d$ is calculated and, consequently, V_d is determined by the relation $\frac{\Delta\omega_1 - \Delta\omega_2}{2\pi}\, x = 2V_d$ where $\Delta\omega_1$ and $\Delta\omega_2$ are the frequency differences obtained from the two wave patterns.

RESULTS AND DISCUSSION

The phase and azimuthal velocity are determined by the deformation of the initially launched sine waves. Typical examples of the output of interferometer are shown in Fig. 3(a) for several exciter-receiver spacings while trace (b) depicts the change in the output of the interferometer when the wave is launched in opposite direction. It can be seen that the periodicity of the signals is different in the two cases (Fig.3b) due to azimuthal motion of ions.

Fig.4 depicts the experimentally obtained dispersion curve for the wave propagating in the electron drift direction and in the opposite direction. These results verify the theoretically obtained dispersion relation showing that, in the frequency region $\Omega_{ce} >> \omega >> \Omega_{ci}$, the wave propagating velocity is equal to the ion acoustic velocity in the rotational frame. To corroborate it further, the wave velocity was investigated in He and Ar and was found to be in agreement with the above view point. During the experiment the ion cyclotron frequency for Ar was kept less than 25 kHz while the wave frequency was much higher than this.

In Fig.5 we show the azimuthal velocity of plasma ions, measured from the deformation of the received signals, indicated by blank circles, and plasma rotation velocity due to $\vec{E} \times \vec{B}$ drift without collisions by dash-dot curve as a function of magnetic field. The azimuthal drift velocity of ions is given by Eq.2 where the second term in bracket is the pressure gradient term which, though mathematically appears in the expression, is neglected by most of experimenters. In fact the pressure gradient term cannot be ignored unless

$$\frac{V_p}{V_{\vec{E}\times\vec{B}}} = \frac{T_i/k}{E_r} << 1$$

where V_p is the pressure gradient drift velocity. Under our experimental conditions, for example, at $B = 50$ G, $k = 5.8\ \mathrm{cm}^{-1}$, $E_r = 0.18$ V/cm and if $T_i \simeq 0.1$ eV, $\frac{T_i/k}{E_r} \simeq \frac{1}{10}$. Therefore, in our calculations, pressure gradient drift velocity can be neglected.

By observing Fig.6, we notice that the drift velocity determined by the two methods is not in agreement although finite Larmor radius correction has been included in the calculation.4) This discrepancy is not removed even though the collisional effects are included in the velocity determined by radial electric field. Azimuthal ion velocity determined by test wave technique is effected by collisions whereas the velocity corresponding to E_r/B is not. This discrepancy is probably due to the collisional effects, a fact which can help us in determining the collision cross section between ions and neutrals. The collision frequency determined in this way is nearly three times less than the frequency determined from the current available data$^{5)}$ at the ion temperature of 0.1 eV. Therefore, there is a possibility that the total cross section determined by the extrapolation method from the current available data cannot be applied. Instead, the so-called "slowing down" cross section,$^{6)}$ appears to be more appropriate quantity to be used at such low energies. Exhaustive calculations, including cylindrical effects, are underway to determine this effect more clearly.

CONCLUSION

Experimental data show a disagreement between the velocity determined by two methods. The velocity determined by Langmuir probe does not include collisions while the velocity calculated by ion acoustic wave includes collisional effects. The disagreement is natural but the due inclusion of collisional effects (determined by the extrapolation method from the current available data) in the Langmuir probe calculations does not remove the disagreement showing that the collision cross section obtained by this method is not the appropriate quantity. Therefore, at low energies, instead of total collision cross section, slowing down cross section should be used. Also in low magnetic field regions where ion Larmor radius and $\frac{\omega_{\vec{E}\times\vec{B}}}{\Omega_c}$ are large, we must take into account the cylindrical effects which give us the correct plasma motion.

REFERENCES

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FIGURE CAPTIONS

Fig.1. Discharge arrangement.

Fig.2. Block diagram of the apparatus.

Fig.3. (a) Output of the interferometer for different transmitter-receiver spacings. (b) Output of the interferometer when the positions of transmitter and receiver are interchanged.

Fig.4. Dispersion curve (experimental) at B = 32 G.

Fig.5. Azimuthal velocity as a function of magnetic field, dash-dot curve shows the velocity determined by the Langmuir probe ($V_{\vec{E}\times\vec{B}}$) and blank circles represent the velocity found by test wave technique.

Discharge Arrangement

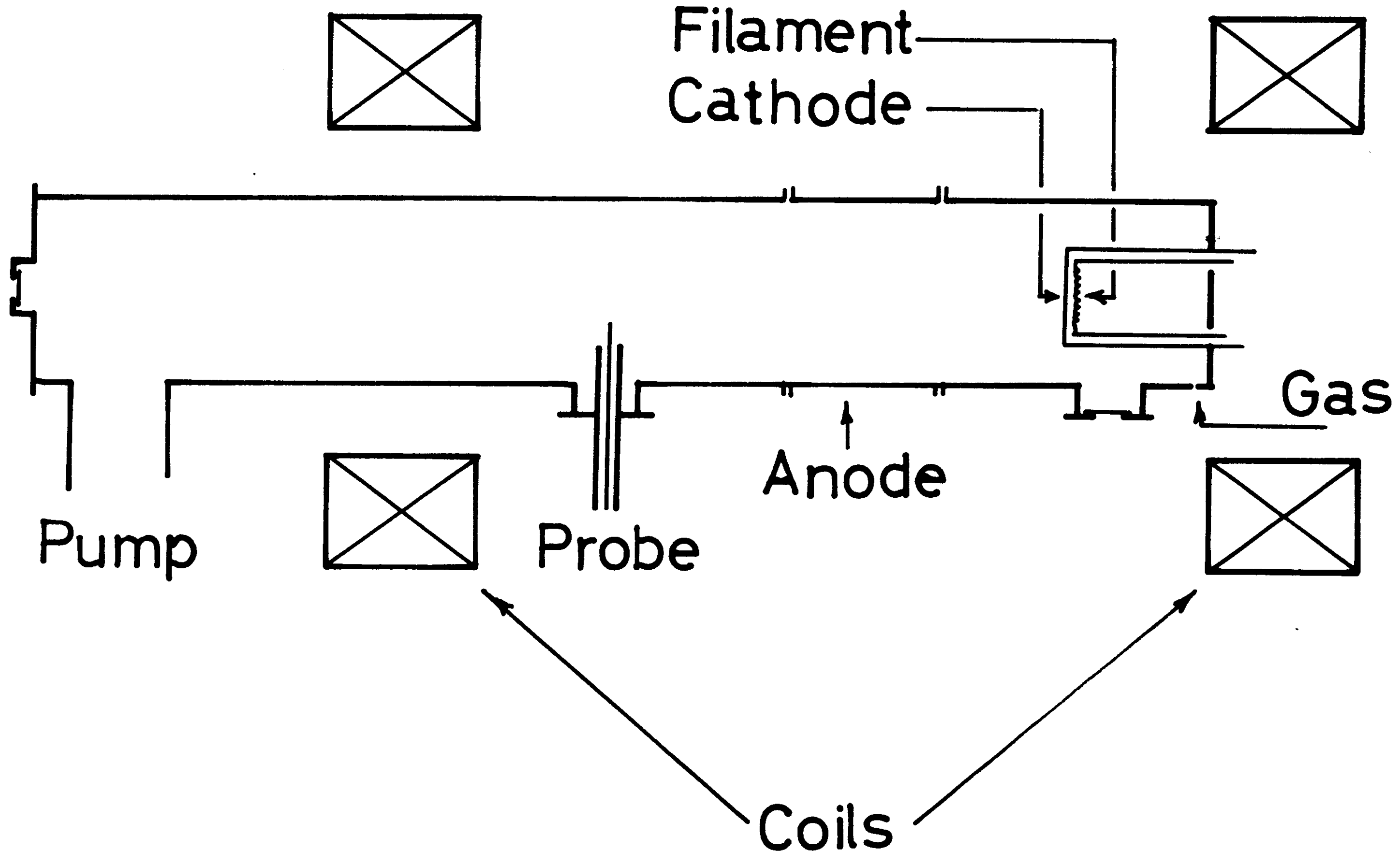

Fig.1

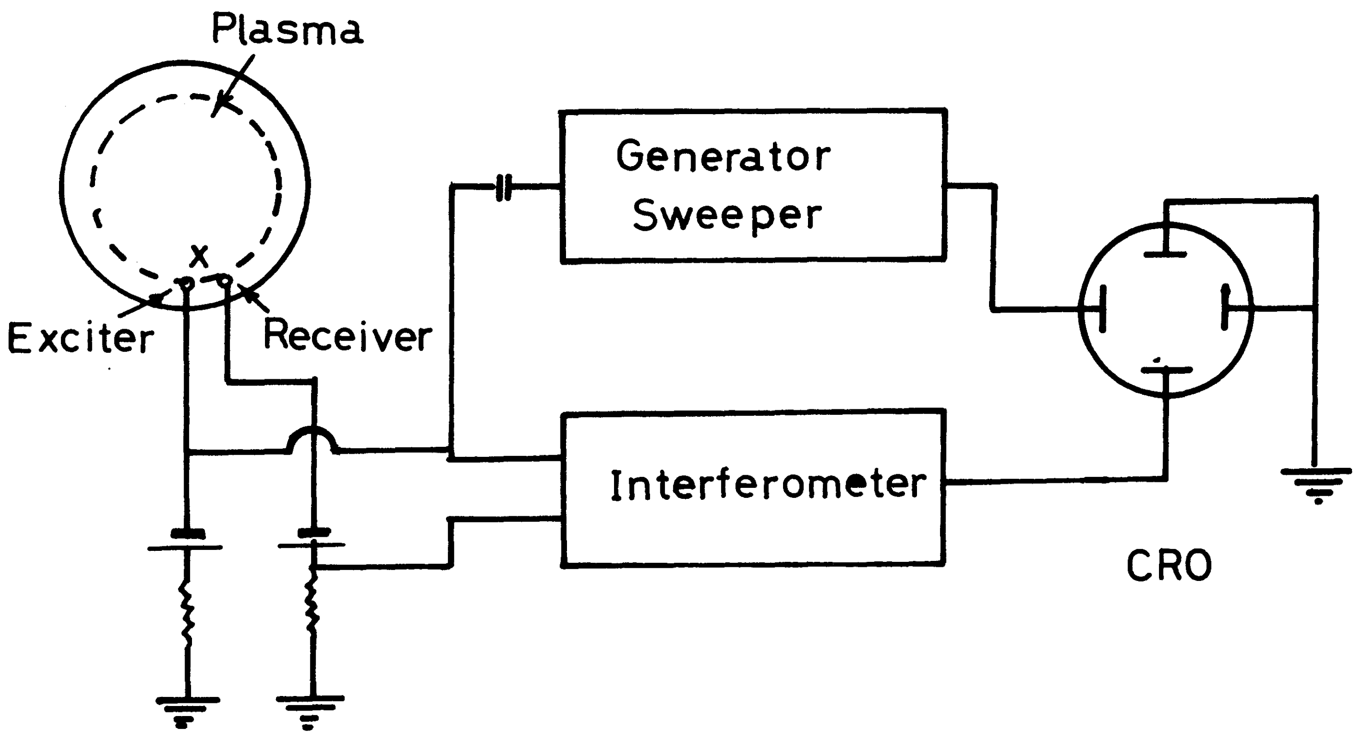
Plasma
x
Exciter
Receiver
Generator
Sweeper
Interferometer
CRO

Fig. 2

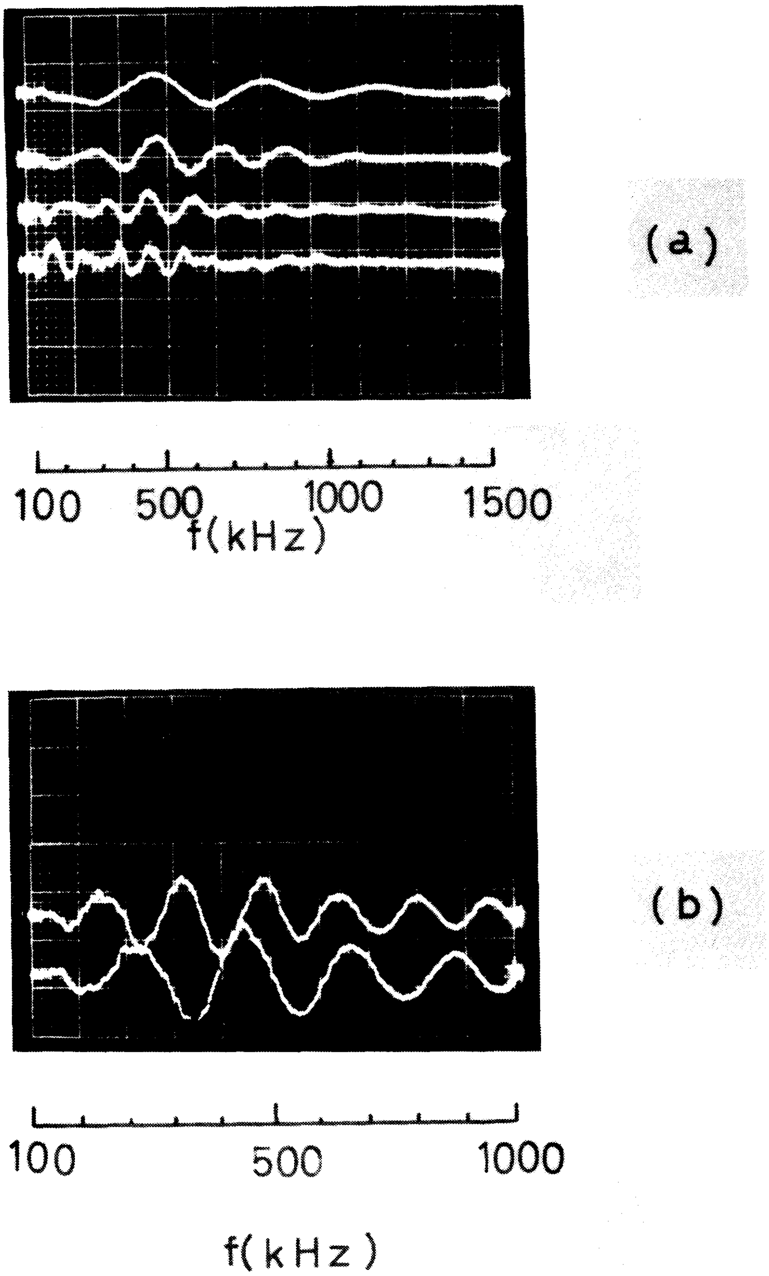

Fig. 3

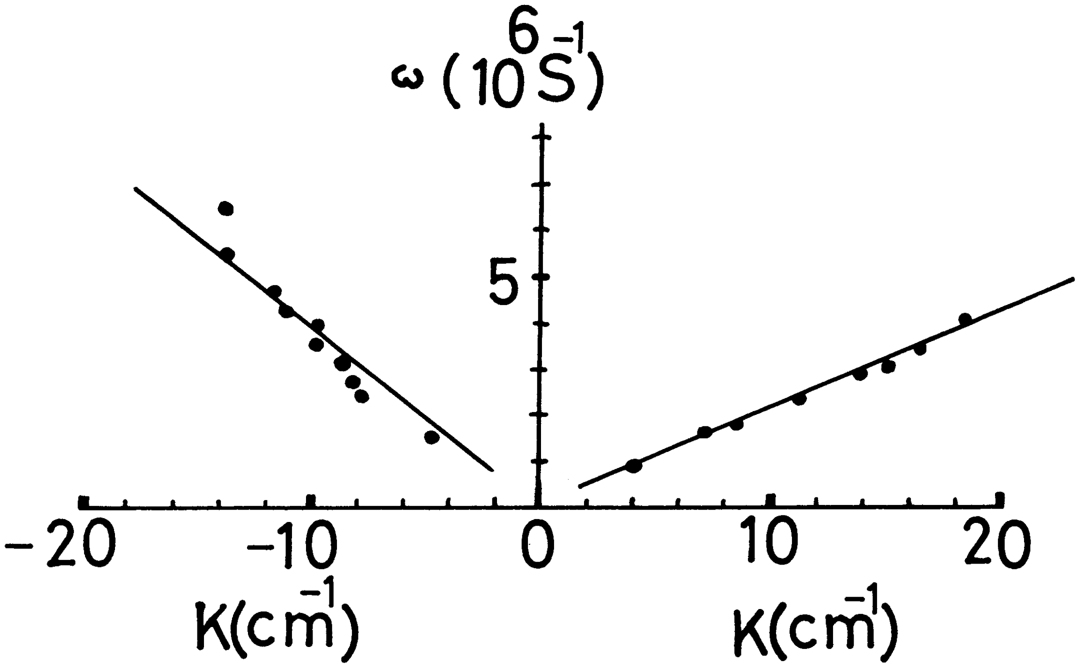

Fig. 4

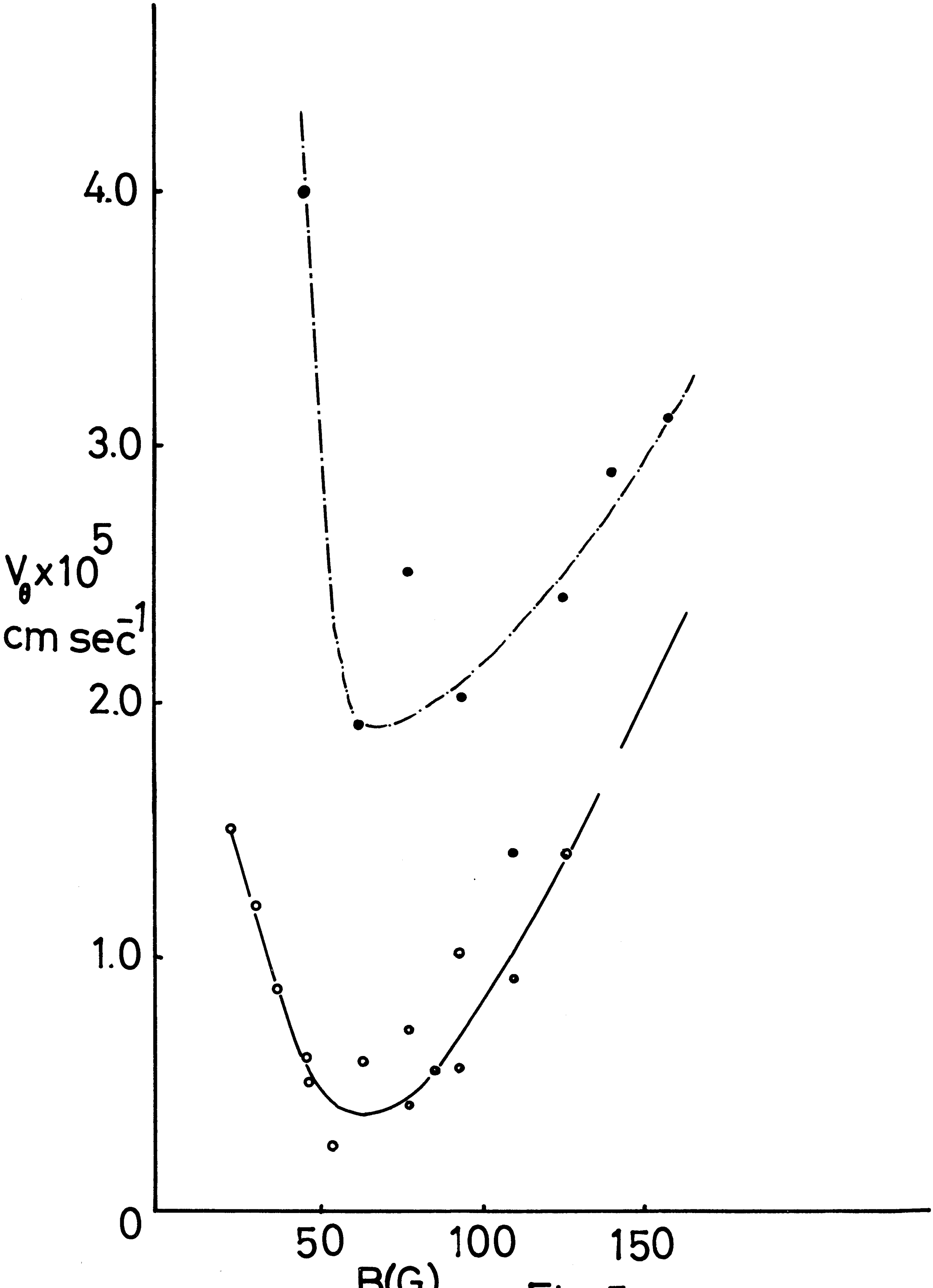

Fig. 5