

Investigation of Particle Velocities in a ‘Critical Velocity’ Rotating Plasma

G. Himmel, E. Möbius, and A. Piel

Ruhr-Universität Bochum, Institut für Experimentalphysik II

(Z. Naturforsch. **32 a**, 577–579 [1977]; received March 25, 1977)

The velocities of helium ions and neutrals are derived from Doppler shifted spectral lines He II 4686 Å and He I 5876 Å respectively. The ion velocity proves to be in accordance with the speed of rotating spokes which are usually observed in the build-up phase of rotating plasmas. It is demonstrated that the spoke velocity represents the plasma mass motion. Braking of plasma motion and acceleration of the neutrals to a value near Alfvén’s critical velocity occurs within 10 μ s.

Introduction

The voltage limitation which has been observed in partially ionized rotating plasmas is usually interpreted in terms of a critical velocity¹ v_{cr} for the relative motion between a magnetized plasma and the neutral gas background. There has been strong evidence that an enhanced collisionless interaction between plasma and neutral gas occurs as soon as the plasma drift velocity exceeds the threshold value $v_{cr} = (2 W_i/m_i)^{1/2}$ (W_i being the ionization energy, m_i the ion mass). The braking of a plasma penetrating a neutral gas to the critical velocity recently has been demonstrated in a linear plasma gun². A similar situation occurs in the build-up phase of a homopolar device when a rotating spoke penetrates the neutral gas background. Although the spoke velocity has already been determined by means of Langmuir probes³ and a framing camera⁴ up to now no direct measurements of particle velocities have been reported. It will be shown below that time resolved Doppler shift measurements of helium ion and neutral lines can give direct information about the plasma-gas interaction. This method, however, is limited to the range of discharge parameters where HeI and HeII lines are emitted with sufficient intensities.

Experimental

The rotating helium plasma is generated in a homopolar cell, similar to Fahleson’s⁵ device, with concentric electrodes of 12 cm and of 5 cm diameter respectively. The outer electrode is acting as anode.

Reprint requests to A. Piel, Institut für Experimentalphysik II, Universität Bochum, Postfach 2148, Gebäude NB 5/132, D-4630 Bochum-Querenburg.

The insulating end plates are separated by 12 cm. The plasma is operated at a pressure near 0.07 Torr. The discharge characteristics of this device at low discharge currents and the plasma parameters in a similar device have been reported earlier^{3, 6}. The evolution of the discharge at currents above 5 kA can be divided into three phases (Figure 1).

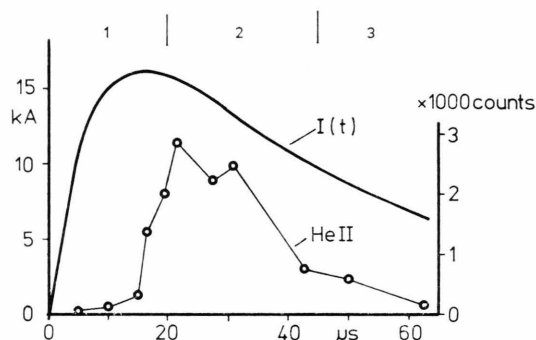


Fig. 1. Discharge current and total line intensity of the helium ion line 4686 Å. The discharge is divided into three phases.

The build-up phase (1) is characterized by a rotating spoke which spreads and forms a uniform plasma disc after 2 to 3 revolutions. In phase (2) nearly complete single ionization is obtained as indicated by a strong emission of the HeII 4686 Å line. In the decay phase (3) a partially ionized plasma remains.

A 1 m grating monochromator is combined with a 500 channel optical multichannel analyzer. The image converter section of the detector head can be operated as a fast shutter which allows a complete line profile to be characteristically recorded within 3 μ s.



Dieses Werk wurde im Jahr 2013 vom Verlag Zeitschrift für Naturforschung in Zusammenarbeit mit der Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. digitalisiert und unter folgender Lizenz veröffentlicht: Creative Commons Namensnennung-Keine Bearbeitung 3.0 Deutschland Lizenz.

Zum 01.01.2015 ist eine Anpassung der Lizenzbedingungen (Entfall der Creative Commons Lizenzbedingung „Keine Bearbeitung“) beabsichtigt, um eine Nachnutzung auch im Rahmen zukünftiger wissenschaftlicher Nutzungsformen zu ermöglichen.

This work has been digitalized and published in 2013 by Verlag Zeitschrift für Naturforschung in cooperation with the Max Planck Society for the Advancement of Science under a Creative Commons Attribution-NoDerivs 3.0 Germany License.

On 01.01.2015 it is planned to change the License Conditions (the removal of the Creative Commons License condition “no derivative works”). This is to allow reuse in the area of future scientific usage.

Doppler Shift Measurements

Side-on measurements along a chord which bisects the electrode spacing of the HeI 5876 Å line are shown for both clockwise and counterclockwise plasma rotation in Figure 2. The shape of the line profile is decomposable into an unshifted component originating from cold wall layers and a hot Doppler shifted plasma line. In a first approach the line shape is assumed to be affected only by thermal

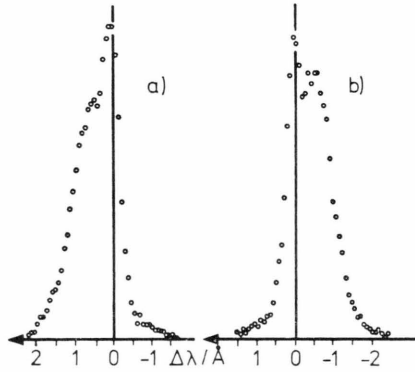


Fig. 2. Profile (side-on) of the HeI 5876 Å line for clockwise (a) and counterclockwise (b) plasma rotation.

broadening and the measured profile is approximated by a dual Gaussian in a least squares fit.

$$L(\Delta\lambda) = a_1 \exp \left\{ - \left(\frac{\Delta\lambda}{\Delta\lambda_1} \right)^2 \right\} + a_2 \exp \left\{ - \left(\frac{\Delta\lambda - \Delta\lambda_0}{\Delta\lambda_2} \right)^2 \right\} + b.$$

Extending a method described by van Zandt et al.⁷ the line widths $\Delta\lambda_1$, $\Delta\lambda_2$ and the shift $\Delta\lambda_0$ are optimized by iteration while the amplitudes a_1 , a_2 and the background b can be calculated by linear regression. The mean neutral velocity is obtained from the Doppler shift $\Delta\lambda_0$. The ion velocity results from the Doppler shift of the HeII 4686 Å line (Figure 3).

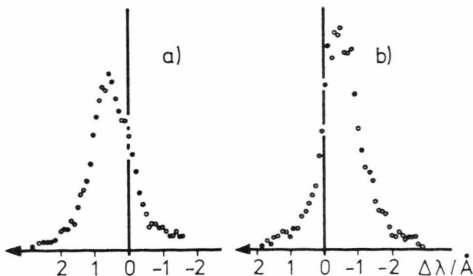


Fig. 3. Profile (side-on) of HeII 4686 Å line (see Fig. 2).

Ion and neutral gas temperatures up to 25 eV have been obtained after correcting for instrument width and Stark broadening.

Results

The measured velocities are compiled in Figure 4. The average E/B velocity, which is derived from the burning voltage according to $E = U/(r_0 - r_i)$ (r_0 , r_i being the electrode radii)⁶, approaches v_{cr} within 10 μs. The ions corotate with the luminous front at the E/B velocity. Thus it is demonstrated that the spoke velocity represents not only the phase velocity of an ionizing front but the plasma mass velocity.

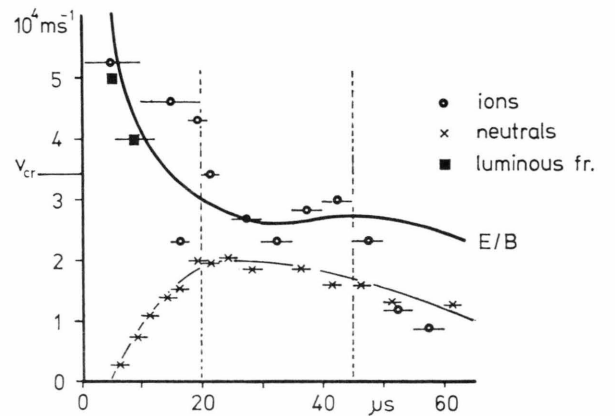


Fig. 4. Comparison of ion and neutral atom velocities with E/B and luminous front speed. The exposure time is indicated by horizontal bars.

During the first 10 μs of the discharge a typical situation for the critical velocity phenomenon is realized when a magnetized plasma penetrates a neutral gas at velocities greater than v_{cr} . The observed braking of plasma motion and accelerating of the neutrals confirm a strong plasma-gas interaction. It is demonstrated in this experiment, that a causal connection between the braking and the voltage limitation exists.

A quasisteady state of an almost fully ionized plasma rotating at a velocity close to v_{cr} can be maintained in phase (2). In the decay phase (3) the ion motion is slowed down to the decreasing neutral velocity.

Conclusions

The azimuthal velocities of ions and neutrals in a rotating plasma at high currents are for the first

time determined directly from Doppler shifted spectral lines and can be compared with simultaneously measured spoke and E/B velocities. It is demonstrated that, in the build-up phase, braking of the plasma motion to a value near Alfvén's critical velocity occurs. This braking is associated with a strong transfer of drift energy to the neutral gas. Rapid electron heating, which was observed in the linear gun experiment², is expected in the present case to be responsible for the fast rise of plasma density during the build-up phase and for the high intensity of the HeII line. We attribute the limita-

tion of the plasma velocity in the fully ionized phase to the action of the critical velocity phenomenon in partially ionized wall layers⁸. This will be subjected to further investigations.

Acknowledgements

We are grateful to Prof. Dr. H. Schlüter for valuable discussion and encouragement in this work. The investigations are part of the joint efforts within the Sonderforschungsbereich 162 "Plasma-physik Bochum/Jülich".

¹ H. Alfvén, On the Origin of the Solar System, Oxford Univ. Press 1954.

² L. Danielsson and N. Brenning, Phys. Fluids **18**, 661 [1975].

³ G. Himmel and A. Piel, J. Phys. D **10** 108 [1973].

⁴ P. B. Barber, D. A. Swift, and B. A. Tozer, J. Phys. D **5**, 693 [1972].

⁵ U. V. Fablesen, Phys. Fluids **4**, 123 [1961].

⁶ G. Himmel, E. Möbius, and A. Piel, Z. Naturforsch. **31a**, 934 [1976].

⁷ J. R. van Zandt, J. C. Adcock, and H. R. Griem, Phys. Rev. A **14**, 2126 [1976].

⁸ B. Lehnert, J. Bergström, and S. Holmberg, Nucl. Fusion **6**, 231 [1966].