Extraction of K⁻ Mesonlike Particles from a D₂ Gas Discharge Plasma in Magnetic Field

J. Uramoto

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Extraction of $K^-$ mesonlike Particles from a $D_2$ gas
Discharge Plasma in Magnetic Field

Jōshin URAMOTO

National Institute of Fusion Science,
Nagoya 464-01, Japan

Abstract

From the outside region of $D_2$ gas discharge plasma along magnetic field, $K^-$ mesonlike particles are extracted with $D^-$ ions and $\pi^-$ mesonlike particles. Then, a higher positive bias voltage is necessary for the beam collector of magnetic mass analyzer in order to detect the $K^-$ mesonlike particles, and we must interrupt the diffusion of the positive ions to the back of the beam collector.

Keywords: $K^-$ mesonlike particle, $D_2$ gas discharge, $D^-$ ion
It has been reported\(^1\) already that negative pionlike particles ($\pi^-$) are extracted from the outside region of a H\(_2\) or D\(_2\) gas discharge plasma in magnetic field, together with H\(^-\) ions or D\(^-\) ions. However, physical differences between the H\(_2\) and the D\(_2\) gas discharge plasma were not investigated precisely under various experimental conditions. In this paper, a remarkable difference of extraction of negatively charged particles between a H\(_2\) and D\(_2\) gas discharge plasma will be clarified by adjusting a bias voltage of the beam collector of magnetic mass analyzer.

A schematic diagram of the experimental apparatus is shown in Fig. 1. The apparatus is constructed from a D\(_2\) gas discharge plasma in magnetic fields, three extraction electrodes (with an aperture of 3 mm in diameter) to extract some negatively charged particles and a magnetic mass analyzer (90° deflection-type).

An electron acceleration-type sheet plasma\(^2\) is produced to generate D\(^-\) ions effectively and in wide area. That is, the discharge (cylindrical) plasma flow of about 1 cm in diameter is transformed into a sheet plasma flow of about 3 mm in thickness and about 20 cm in width, while the electron components in the initial discharge plasma are accelerated near 80 eV. The sheet plasma flow passes through the electron acceleration anode (12 in Fig. 1) and enters the main chamber (50 cm long). The electron components in the sheet plasma are reflected by the end plate which is electrically floated. A uniform magnetic field of about 50 gauss is applied along the sheet plasma flow in the main chamber where the D\(_2\) gas pressure is about $1.5 \times 10^{-3}$ Torr. The electron acceleration anode current $I_A$ is 30A and about 60% of $I_A$ enters the main chamber. A distance between the sheet plasma center and the first extraction electrode (L) is 7.5 cm. The plasma density in the center of the sheet plasma is about $10^{11}$/cc and the electron temperature is about 20 eV. The positive ion density in front of the first extraction electrode is estimated to be about $10^{10}$/cc from a positive ion saturation current as D\(_3^+\), while the electron density from the Langmuir probe characteristic is about $10^9$/cc and the electron temperature is about 3.0 eV. That is, the electron density in front of the first extraction electrode is reduced near 1/10 of the positive ion density.

The negatively charged particles extracted from the D\(_2\) gas discharge plasma, are injected into the ordinary magnetic mass analyzer (MA) through the slit (3 mm × 1 cm) while each mass of the negatively charged particle is estimated by the following relations: From the analyzing magnetic field $B_M$ where the negative current to the beam collector BC shows a peak, the curvature radius $r$
of the mass analyzer and the extraction (acceleration) voltage $V_E$, we can estimate the mass $m$ of the negatively charged particle by,

$$ m = \frac{Ze (BMr)^2}{2V_E} $$

$$ = \frac{8.8 \times 10^{-2} Z (BMr)^2 m_e}{V_E}, \hspace{1cm} \text{(1)} $$

where $e$ is the electron charge, $BM$ is in gauss unit, $r$ is in cm unit, $V_E$ is in volt unit and $m_e$ is the electron mass and $Z$ is the charge number. For the curvature radius $r = 4.3$ cm of this mass analyzer, the Eq. (1) is rewritten by

$$ m = \frac{1.63 Z BM^2}{V_E} m_e. \hspace{1cm} \text{(2)} $$

In the extraction of negatively charged particles, the first extraction electrode (L) is electrically floated, whose potential $V_L$ is about $-15$V with respect to the electron acceleration anode (12 in Fig. 1). A potential $V_M$ of the second extraction electrode (M) is kept at $300$V. The potential $V_E$ of the final extraction electrode (E) is $800$V.

A result of the mass analysis for extraction of negatively charged particles from the D$_2$ gas discharge plasma, is shown in Fig. 2. Dependences of the negative current $I^-$ to the beam collector on the analyzing magnetic field $BM$ are shown, where the bias voltage $V_{BC}$ of the beam collector with respect to the mass analyzer, is $50$V or $140$V.

For $V_{BC} = 50$V [(1) of Fig. 2], the first peak of negative current $I^-$ to the beam collector is seen at $BM = 390$ gauss while the second peak appears at $BM = 1420$ gauss. From Eq. (2), we obtain $m_1 = 310 m_e$ and $m_2 = 4100 m_e$, assuming that $Z = 1$. On the other hand, for $V_{BC} = 140$V [(2) for Fig. 2], the third peak appears at $BM = 720$ gauss between the first peak and the second peak, which corresponds to $m_3 = 1050 m_e$, assuming that $Z = 1$.

For the above experimental results of Fig. 2, we can estimate that the first particle mass ($m_1$) is near the typical negative pion $\pi^-$ mass ($= 273 m_e$) within 14% and the second particle mass ($m_2$) is near $D^-$ ion mass ($= 3680 m_e$) within 12%. Here, we find that the third particle mass ($m_3$) is near the typical $K^-$ meson mass ($= 966 m_e$) within 9%, assuming that $Z = 1$ also.
In the experiment of Fig. 3, a Cu plate of 0.5 mm in thickness is put in front of the beam collector of the mass analyzer. Then, the second current peak corresponding to $D^-$ ion disappears while the first and the third current peak appear. This experimental fact shows that the pionlike particle $\pi^-$ and the $K^-$ mesonlike particle penetrate the Cu plate. It has been reported already that the pionlike $\pi^-$ or muonlike particle $\mu^-$ penetrates a metal plate if the positive ions exist behind the metal plate. In this experiment, those positive ions may be produced by the gas ionization due to $D^-$ ions. From these experimental results, we find that a physical character of the first peak particle ($\pi^-$) and the third peak particle ($K^-$) is remarkably different from that of the second peak particle ($D^-$).

Next, in order to clarify differences for the third peak ($K^-$) between a $D_2$ gas and $H_2$ gas discharge plasma, extractions of negatively charged particles from a $H_2$ gas discharge plasma are tried under experimental conditions similar to the $D_2$ gas discharge plasma (that is, $B_Z = 50$ gauss, $I_A = 30A$, $V_M = 300V$ and $P = 1.5 \times 10^{-3}$ Torr of $H_2$ gas). The experimental results for the $H_2$ gas discharge plasma are shown in Fig. 4 (in the ordinary method) and in Fig. 5 (in the "Cu plate arrangement" method). In Fig. 4, the first current peak (corresponding to $\pi^-$) and the second current peak ($H^-$) are seen under the beam collector bias voltage $V_{BC} = 50V$ and $V_{BC} = 140V$. In Fig. 5, only the first current peak ($\pi^-$) is seen. As understood from these experimental results, the third current peak corresponding to the $K^-$ mesonlike particle does not appear for $H_2$ gas discharge plasmas. We have confirmed that the $K^-$ mesonlike particles are not extracted from $H_2$ gas discharge plasmas even if the experimental conditions are varied greatly.

A dependence of the $K^-$ mesonlike current peak to the beam collector on the extraction voltage $V_E$ is investigated from 700V to 1200V, which satisfies Eq (2). The $K^-$ mesonlike current peak does not appear for $V_E < 700V$ while the $\pi^-$ current peak does not appear for $V_E < 400V$. That reason may be due to the life time ($= 1.2 \times 10^{-8}$ sec) of $K^-$ meson which is shorter than that of $\pi^-$ meson ($= 2.6 \times 10^{-8}$ sec).

In conclusion, the $K^-$ mesonlike particles generate as some physical differences between the $H_2$ gas and $D_2$ gas discharge plasma. A higher positive bias voltage of the beam collector is necessary to detect the $K^-$ mesonlike particles and we must interrupt the diffusion of the positive ions to the back of the beam collector \(^{4)}\) (Fig. 2 MA ).
References


Figure Captions

Fig. 1 Schematic diagram of experimental apparatus.

Fig. 2 Dependences of negative current Γ to beam collector on magnetic field intensity Bₘ of MA at Vₑ = 800V. (1): Vₐ = 50V. (2): Vₐ = 140V.
π⁻: First peak of Γ corresponding to negative pionlike particle. Δ⁻: Second peak of Γ corresponding to deuteron negative ion. K⁻: Third peak of Γ corresponding to K⁻ mesonlike particle.

Fig. 3 Dependences of negative current Γ on Bₘ under a case setting a Cu plate in front of beam collector at Vₑ = 800V. π⁻: First peak of Γ. K⁻: Third peak of Γ. (Δ⁻): Position of second peak of Γ. Cu: Copper plate of 0.5 mm in thickness, which shields the surface of beam collector. (1): Vₐ = 50V. (2): Vₐ = 140V.

Fig. 4 Dependences (for H₂ gas) of negative current Γ on Bₘ at Vₑ = 800V.
Fig. 5 Dependences (for H$_2$ gas) of negative current $\Gamma^-$ on $B_M$ under a case setting a Cu plate in front of beam collector at $V_E = 800$V.

(1): $V_{BC} = 50$V. (2): $V_{BC} = 140$V. $\pi$: First peak of $\Gamma^-$. 
Appendix

Schematic diagrams of the magnetic mass analyzer and the extraction electrodes are shown in Fig. 1 MA and Fig. 2 MA. The (fringe) magnetic field distribution is shown in Fig. 3 MA also.
Figure Captions of Appendix

Fig. 1 MA and Fig. 2 MA  Schematic diagrams of mass analyzer M.A. and the extraction electrodes E.M.L.


Fig. 3 MA  Fringe magnetic field distribution at (1A of M.A. coil current).

$B_M$: Analyzing magnetic field of M.A. $B_0$: Uniform magnetic field inside of M.A. S: Entrance slit position. X: End of uniform magnetic field.
Fig. 3 MA
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