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Construction of Rb Charge Exchange Cell and Characteristic Experiment for He^- Ion Production

Hee–Seock LEE, Jun–Gyo BAK and Hae–iLL BAK
Department of Nuclear Engineering, Seoul National University
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He음이온 생성을 위한 Rb전하교환기의 제작 및 특성실험

이희석 · 박준교 · 박혜일
서울대학교 원자핵공학과
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Abstract

The Rb charge exchange cell is constructed as the He^- ion source of the SNU 1.5-MV Tandem Van de Graaff accelerator. The characteristic experiment is carried out in order to determine the optimum operational conditions of the cell. The He^+ ion beam with the energy of 1~10 keV, extracted from the duoplasmatron ion source, is passed through the Rb vapor to become He^- ions by the two step charge exchange reaction, i.e., $He^+ + Rb \rightarrow He^{o*} + Rb^+$ and $He^{o*} + Rb \rightarrow He^- + Rb^+$. From the experimental results, it is found that the maximum fractional yield of He^- ions is produced at He^+ ion energy of 7 keV. The optimum temperatures of the oven and the canal are determined to be 370 ℃ and 95 ℃ respectively. Under the optimum operational condition the maximum fractional yield of He^- ions is 2.42±0.02%. This charge exchange cell is proved to be an effective system for the production of He^- ions.

요 약

SNU 1.5-MV 직렬형 반데그라프 가속기의 헬륨음이온원으로서 Rb 전하교환기를 제작하였다. 교환기의 최적운전조건을 결정하기 위해 특성실험을 수행하였다. Duoplasmatron 이온원에서 인출된 1~10 keV 에너지의 헬륨양이온빔을 Rb 증기속에 통과시킴으로써 2 단계 전하교환반응, 즉 $He^+ + Rb \rightarrow He^{o*} + Rb^+$ 과 $He^{o*} + Rb \rightarrow He^- + Rb^+$에 의해 헬륨음이온을 얻었다. 실험결과로부터 헬륨음이온의 최대생성률이 헬륨양이온에너지가 7 keV일때 얻어짐을 알 수 있었다. Oven과 Canal의 최적온도는 각각 370 ℃와 95 ℃로 결정되었다. 최적동작조건하에서 최대 헬륨음이온 생성률은 2.42±0.02 %이었다. 본 전하교환기는 헬륨음이온생성에 효과적인 장치임이 입증되었다.

Ⅰ. Introduction

For the last few years, several experiments such as the measurements of X-ray production cross–sections(1), the trace element analysis by PIXE(Proton Induced X–ray Emission) method(2) and the surface analysis by RBS(Rutherford Backscattering Spectrometry) method(3) have been carried out using the proton beam from the SNU

1.5-MV Tandem Van de Graaff accelerator. In the application of RBS, an alpha beam has higher resolution than a proton beam(4). So, it was necessary to construct a He^- ion source. Because the fractional yield of He^- ions by charge exchange reactions with alkali metals is relatively high as compared with other methods of He^- ion production(5), a charge exchange cell is suitable as the He^- ion source. The duoplasmatron ion source used to produce H^- ions was modified and used to produce He^+ ions. A charge exchange cell using Rb was constructed as the He^- ion source of the SNU 1.5 - MV Tandem Van de Graaff accelerator. The fractional yields of He^- ions were measured when $1\sim10$ keV He^+ ions were incident to the cell. The characteristic experiment of the cell was performed to determine the optimum operational conditions about the temperatures of the canal and the oven which determined the density of Rb vapor in the cell. The intensity measurement of He atom beam was carried out to monitor the incident He^+ ion current during the operation of the charge exchange cell through the measurement of secondary electrons by a secondary emission detector.

Ⅱ. Experimental Procedure

A. Experimental setup

This Rb charge exchange cell was constructed on the basis of NEC charge exchange RF ion source called ‘Alphatross’(6), which was evolved from RF ion source originated with R.H. Richards et al. in 1967(7). The cross-sectional view of the Rb charge exchange cell is shown in Fig. 1 and its design parameters are shown in Table 1. The principle of the heat pipe is the basis of its operating process(8,9). The operating process consists of evaporation, by the heat produced in the oven, and recovery, by gravitation, of alkali metals which have the characteristics of low viscosity and high thermal conductivity.

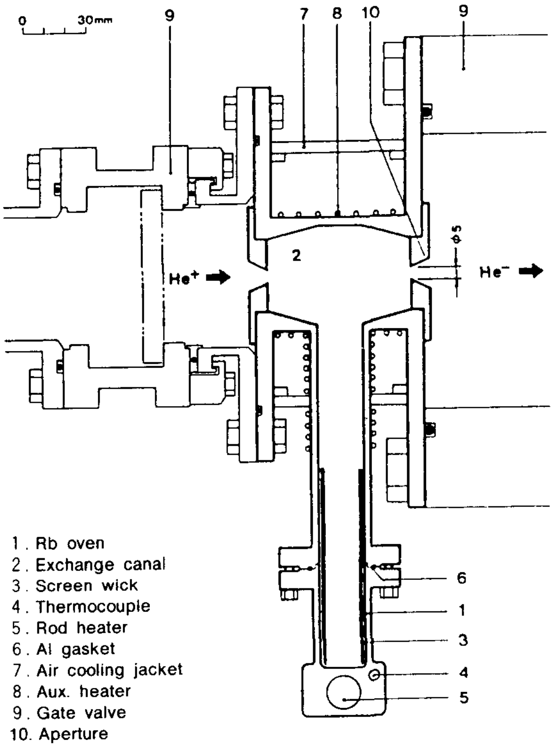


Fig. 1. Cross-sectional view of the Rb charge exchange cell.

For the efficient recovery of liquid Rb, the canal floor is inclined as shown in Fig. 1. When the temperature of the outside of the canal was 70 ℃, those of the inside and the aperture were about $60\sim62$ ℃ and that of the outside of the aperture was about 55 ℃. During the Rb charge exchange cell operation, the system pressure was maintained below 1×10^{-5} Torr. The experimental setup for the characteristic experiment is shown in Fig. 2. The He^+ ion beam extracted from the duoplasmatron ion source was focussed at the center of the Rb charge exchange cell by two einzel lenses. For the separation of He^+, He^0 and He^- beams emerging from the Rb charge exchange cell, an electrostatic charge-state separator was used. The separation phenomena of these beams were observed by the beam profile monitor located between the charge-state separator and the beam detection chamber.

In order to measure the He^+ and He^- ion currents, two Faraday cups were installed at the angles of ±7° to the beam axis. A permanent magnet was used to suppress secondary electrons(10). The entrance diameter of the Faraday cup is 20 mm. The magnetic flux density inside the Faraday cup was 100~400 gauss. The secondary emission detector is shown in Fig. 3 and a permanent magnet was set up to suppress the incident and secondary electrons. The secondary electron capture electrode is 30 mm in diameter and 53 mm in length and its bias voltage was 110~150 V.

Table 1. Design parameters of the Rb charge exchange cell.

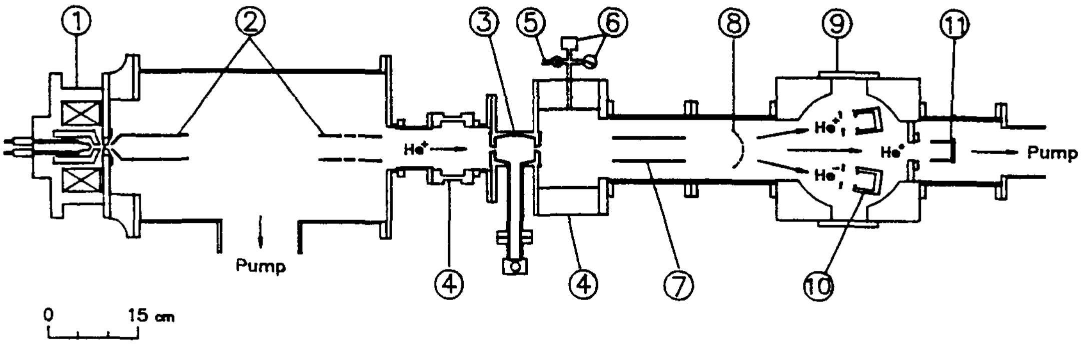
Parameters	Values
Inner diameter of canal	max. 48 mm min. 38 mm
Length of canal	68 mm
Inclination of floor of canal	11.8°
Diameter of aperture	5 mm
Length of chimney	126 mm
Inner diameter of chimney	21.2 mm
Depth of oven	38 mm
Capability of Rb setting	max. 20 g
Power of rod heater (autoregulated)	200 V, 300 W
Resistance of silicon line heater	185.5 Ω
Sensor of temperature	Cromel–Alumel type thermocouple
Type of vacuum tight	Al gasket at oven Viton O–ring at canal

B. Determination of the fractional yield of He^- ion, F^-

Since the variation of He^+ ion current measured behind the charge exchange cell, without the operation of the cell, was below 10 % for 3 hours, the incident He^+ ion current, I^+ , during operation of the cell, could be reasonably determined as

$$I^+ = (I_{after} + I_{before})/2,$$

where I_{after} and I_{before} are He^+ ion currents after and before the operation of the cell. For the inci-



1. Duoplasmatron Ion Source
2. Einzel Lens
3. Rb Charge Exchange Cell
4. Gate Valve
5. Ar Gas Inlet
6. Vacuum Gauge (Penning+Bourdon)
7. Charge Separator
8. Beam Profile Monitor
9. Beam Detection Chamber
10. Magnetically Suppressed Faraday Cup
11. Secondary Emission Detector

Fig. 2. Setup for characteristic experiment of the Rb charge exchange cell.

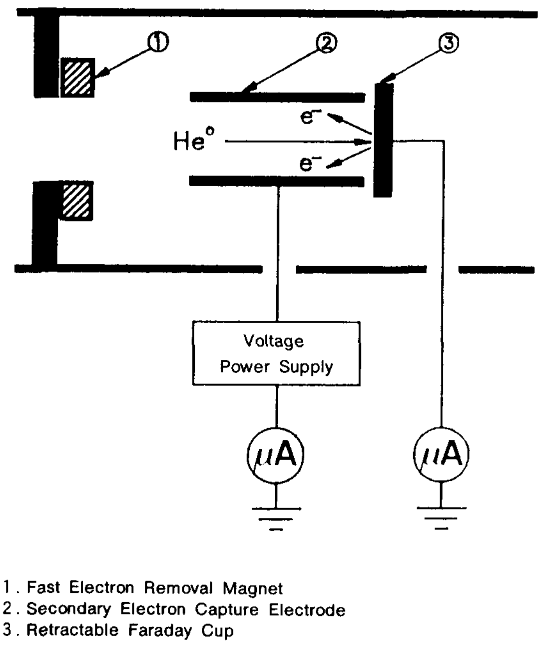


Fig. 3. Schematic diagram of secondary emission detector for determination of He° beam intensity.

dent He^+ ion current of 0.8~8.0 μA, the fractional yield of He^- ion, defined as $F^- = I^-/I^+$, was measured.

Ⅲ. Results and Discussion

The variation of F^- relative to the energy of the incident He^+ ions is shown in Fig. 4. The trend of the variation was consistent with other experimental results(11, 12) and the maximum value of F^- was determined to be 2.42±0.02% at the incident He^+ energy of 7 keV. This value is 1.2~1.5 times as high as the experimental values of other authors(6,11). It is considered that the discrepancy is due to the effects of secondary and incident electrons in the Faraday cup. The cross-section of the charge exchange reaction is proportional to the incident ion energy, but this experiment showed that F^- decreased for energies

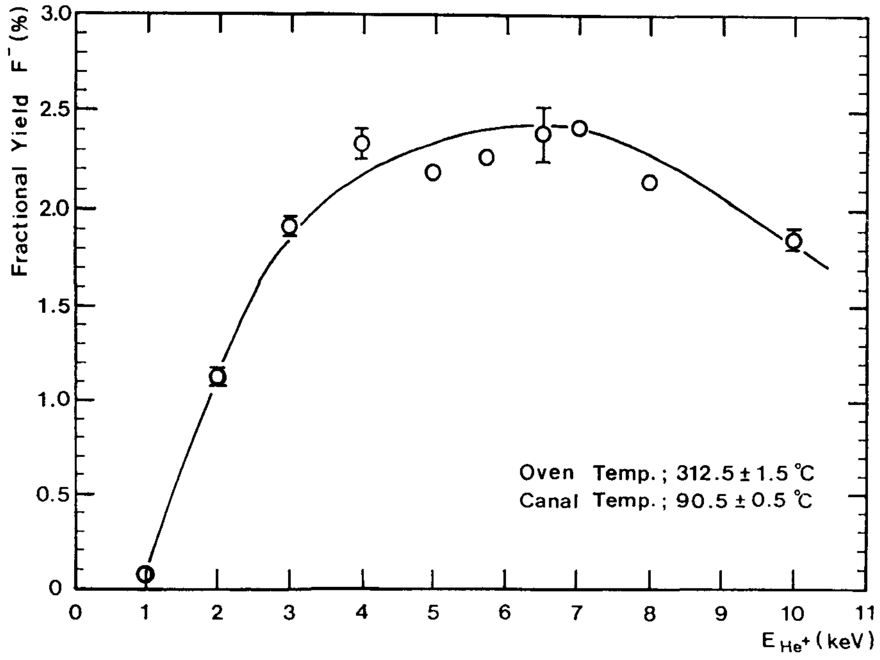


Fig. 4. Fractional yield of He^- ion current relative to incident He^+ ion current measured by separate Faraday cups.

above 7 keV. This phenomenon is thought to be due to the fact that the following reactions are more effective than the He$^-$ production reaction at He$^+$ energies above 7 keV.

$$He^+ + Rb \rightarrow He^+ + Rb^+ + e^-,$$
$$He^+ + Rb \rightarrow He^0 + Rb^{+*}$$

The variations of the He$^-$ ion currents relative to the canal and the oven temperatures are shown in Fig. 5 and Fig. 6. The He$^-$ ion production rate was more sensitive to the canal temperature than the oven temperature. The optimum values of the oven and canal were determined to be 370 ℃ and 95 ℃ respectively. These values were varied slightly according to the residual amount of Rb in the charge exchange cell and the vacuum pressure.

Under the optimum operational condition, the maximum He$^-$ ion current was measured to be 236 nA and it will be increased to 1 μA by improvement of the beam transport system, such as the

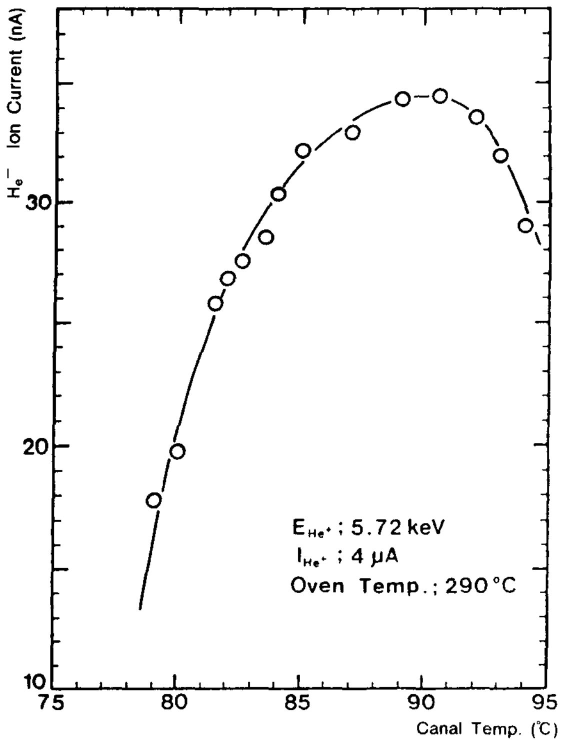


Fig. 5. He$^-$ ion current vs. canal temperature.

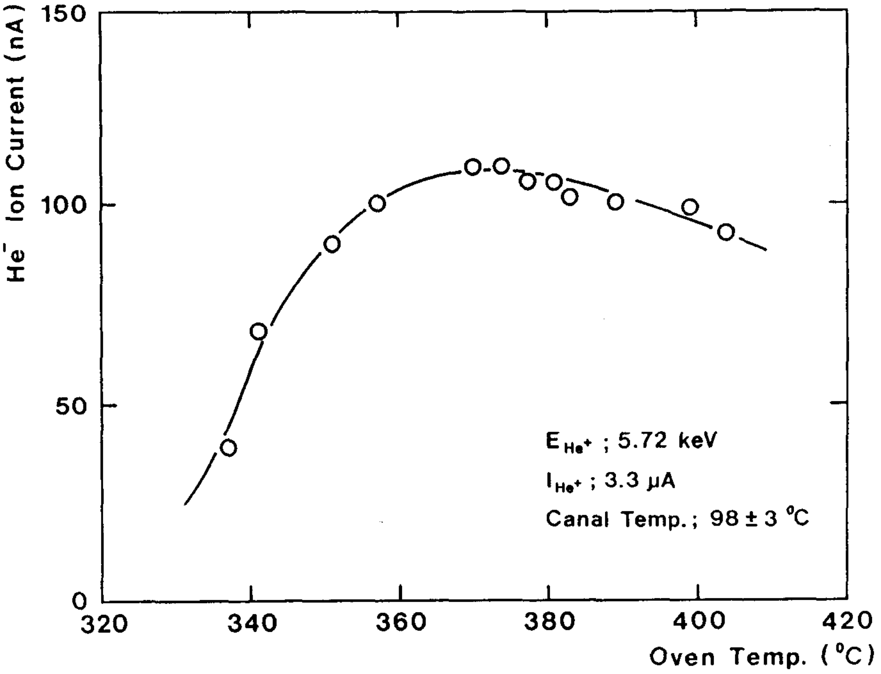


Fig. 6. He$^-$ ion current vs. oven temperature.

fine alignment of two einzel lenses and the installation of an electrostatic beam steerer between them.

Ⅳ. Conclusion

As mentioned above, the results agree well with those of other experiments. In order to determine the F^- value more precisely, it is necessary to install a Faraday cup before the cell to measure the incident He^+ ion current. Through the characteristic experiment, it is confirmed that this cell is suitable as the He^- ion source of the SNU 1.5-MV Tandem Van de Graaff accelerator.

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