PRODUCTION OF NEGATIVE HELIUM IONS BY NEARLY-RESONANT CHARGE EXCHANGE IN POTASSIUM

R. M. Ennis, Jr., D. E. Schechter, G. Thoeming, and D. B. Schlafke
ORTEC Incorporated, Oak Ridge, Tennessee

and

B. Donnally
Lake Forest College, Lake Forest, Illinois

Summary

The design criteria for a source of 5—10µA of He^- ions suitable for tandem accelerator application have been investigated. The process used is a nearly-resonant charge exchange between He^+ ions, from a duoplasmatron, and potassium vapor. In the He^+ energy range of 5—25 keV, the He^-/He^+ yield has been measured as a function of He^+ energy. Yields of ~2% have been observed. A He^- beam emittance of 1.2×10^{-2} cm rad $eV^{1/2}$ has been measured. The potassium flux into the system was found to be $\sim 10^{16}$ particles/s.

Introduction

Donnally[1] first suggested, and also first demonstrated experimentally, a nearly-resonant charge transfer process[2] for obtaining intense He^- ion beams. The process is characterized by a high yield and a minimal associated gas loading of the vacuum system. This has induced a detailed investigation at ORTEC of the suitability of this process as a source of He^- ions for tandem accelerators. The process reactions suggested by Donnally are:

$$He^+ + X^0 \longrightarrow He(1s2s)^3S_1 + X^+$$

$$He(1s2s)^3S_1 + X^0 \longrightarrow He^-(1s2s2p)^4P_{5/2} + X^+$$

Donnally has also suggested the use of either cesium or potassium vapor as the medium for the nearly resonant charge transfer. Results of the investigation of the process using potassium vapor will be reported here.

Discussion of Investigation

The apparatus shown schematically in Figure 1 was used to measure the He^-/He^+ yield as a function of He^+ energy. In the initial investigations, no collimation was employed between the duoplasmatron—Einzel lens combination and the potassium cell. Under these circumstances a significant variation in fractional He^- yields was observed, particularly at He^+ energies below 15 keV. These variations were directly correlated to differences in the Einzel lens-to-potassium cell distance. Such differences were deliberately introduced in a number of experiments. Several possible explanations for this correlation are considered.

No variation in He^- fractional yield due to variation in He^+ current density through the potassium cell was observed. The He^+ current density was varied by changing duoplasmatron parameters. It was thought that the most probable cause of the variation in He^-/He^+ yield was related to the disparity between the emittances of He^+ and He^- beams. Therefore, in order to obtain consistent fractional He^- yields as a function of He^+ energy, collimators were interposed between the Einzel lens and potassium cell. The collimators were spaced 2 cm apart and were 0.15 cm in diam. This resulted in nearly 100% transmission of the collimated He^+ beam through the potassium cell and the subsequent optics of the apparatus. This was verified by measurement using Faraday cups both in front of and behind the potassium cell, as well as at the 0° and 30° positions following the analyzing magnet. A 0.6 cm diam aperture preceded both the 0° and 30° Faraday cups. The potassium cell was 0.3 cm in diam and 3.8 cm long. In order to minimize the neutral potassium flux into the system, a vapor condenser was placed at each end of the cell. The cell temperature was monitored by means of an iron-constantan thermocouple. The beam energy through the analyzing magnet was maintained constant by means of an accelerating gap-Einzel lens combination following the potassium cell. The total flight path to both Faraday cups from the center of the potassium cell was 0.5 m.

The He^-/He^+ yield measured as a function of He^+ energy is plotted in Figure 2. During these experiments, the He^+ concentration of the total ion beam from the duoplasmatron was greater than 95%. This was determined by means of the analyzing magnet. The potassium cell temperature was elevated until an appreciable attenuation of the analyzed He^+ beam was observed. Then the polarity of both the analyzing field and the accelerating gap potential was reversed. The He^- beam current was maximized with potassium cell temperature and allowed to stabilize. The maximum yield at each energy occurred at the same cell temperature (150—160° C). The system pressure was constant at 3×10^{-6} torr during these measurements.

The total He^- yield is plotted as a function of energy in Figure 4. The maximum He^- yield corresponds to a He^0

input to the duoplasmatron of 12 atm cm^3/h. The apparatus shown schematically in Figure 3 was used to measure both the total He^- yield and the He^- beam emittance.

The emittance of the He^- beam was measured by using both the slotted plate and copy paper technique[3] and the slotted plate and scanning wire technique[4]. In both cases the He^- beam energy was 15 keV and beam current was 4μA.

The slotted plate had 20 slots 0.25 mm wide by 38 mm long and center to center spacing of 2 mm. A 0.4 mm wire was scanned at a distance 0.3 cm from the plate. The oscilloscope scan in Figure 5 was obtained. The scan in Figure 6 was obtained at a distance of 14 cm from the slotted plate. From these two scans, an emittance of 1.2 X 10^{-2} cm rad $eV^{1/2}$ was calculated. The copy paper was positioned 30 cm from the slotted plate. Emittance values within 30% of the above value were observed. In his He^- beam emittance measurement at beam energies <4 keV, Donnally[1] determined that the He^- beam emittance is less than 0.1 cm rad $eV^{1/2}$. These measurements were made with the same charge exchange cell dimensions as used at ORTEC. However, the exchange medium was cesium.

The neutral potassium flux out of each end of the cell was measured using the technique of surface ionization on hot tungsten. A 0.5 mm-diam tungsten wire was used. The measured flux was 10^{16} particles/s. This corresponds to a total loss of potassium from the canal of 30 mg/h.

Conclusions

Based upon the results of this investigation, it is concluded that this process for He^- ion production is suitable as a source for tandem accelerators. The dimensions of the exchange cell must be determined by the emittance of the He^+ beam and the vapor loss to the system. Then high He^-/He^+ yields and intense He^- beams of good stability can be obtained. The value of emittance is sufficiently below the admittance of most tandem accelerators that high transmissions should be obtained. However, the neutral potassium flux is great enough to warrant off-axis accelerator injection and/or other measures to eliminate the contamination of source and accelerator by the potassium metal.

Acknowledgement

The authors wish to acknowledge many valuable criticisms and suggestions from Jesse E. Sherwood during the course of this investigation.

References

1. B. Donnally and G. Thoeming, "Helium negative ions from metastable helium atoms." To be published.
2. Patent applied for.
3. R. McKeever, and A. Yokosawa, Rev. Sci. Instr. 33(7):746 (July 1962).
4. P. H. Rose, R. P. Bastide, N. B. Brooks, J. Airey, and A. B. Wittkower, Rev. Sci. Instr. 35(10):1283 (1964).

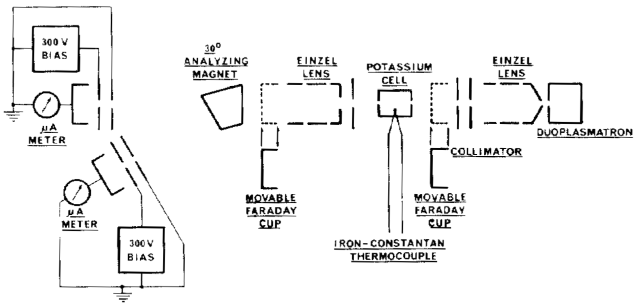

Fig. 1. Apparatus for measuring He^-/He^+ yield vs. He^+ energy.

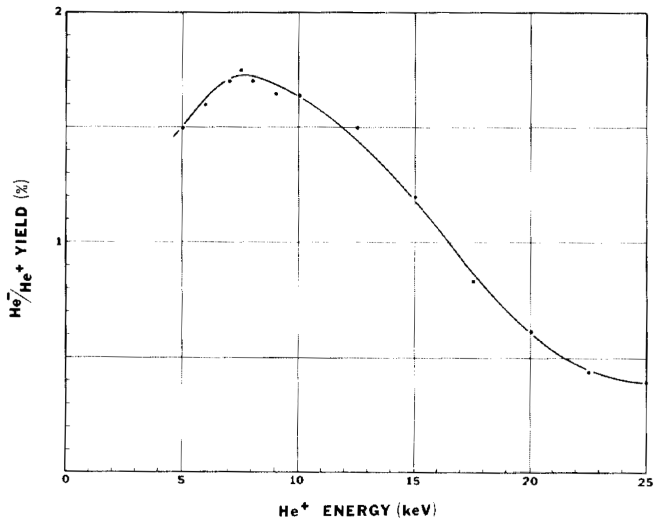

Fig. 2. He^-/He^+ yield vs. He^+ energy.

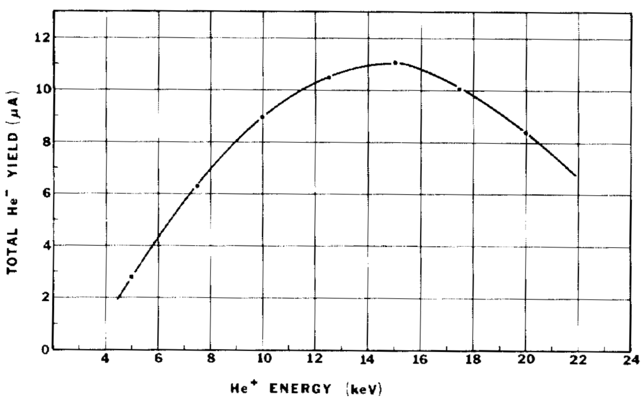

Fig. 3. Total He^- yield vs. He^+ energy.

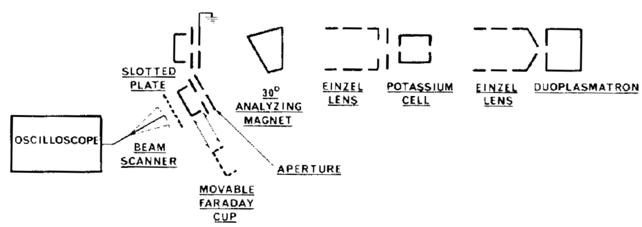

Fig. 4. Apparatus for determining total He^- yield and emittance.

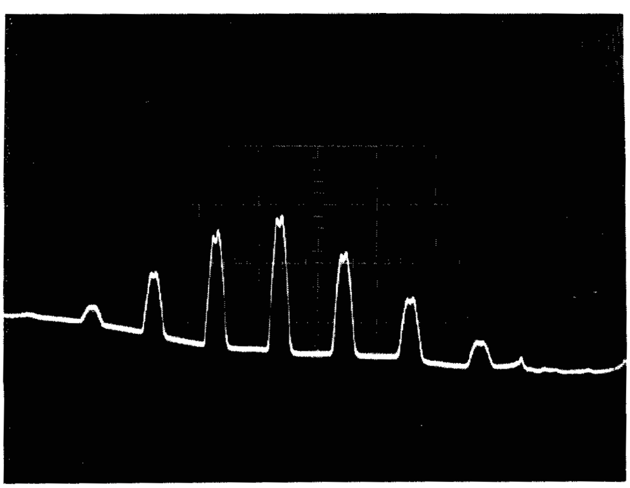

Fig. 5. Beam scan 0.3 cm from slotted plate.

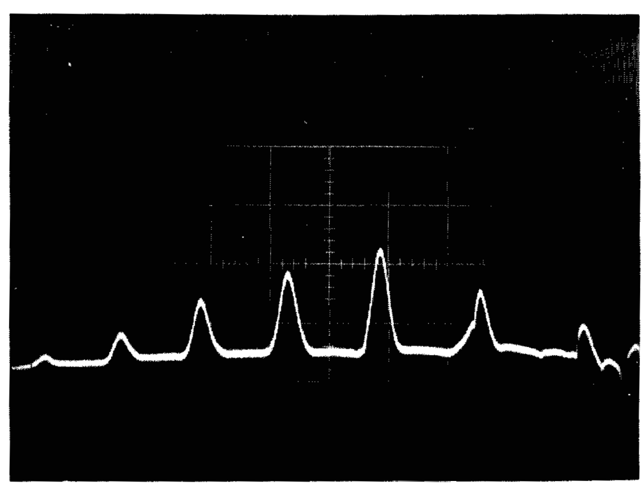

Fig. 6. Beam scan 14 cm from slotted plate.