MODIFICATION OF AN ION SOURCE FOR THE PRODUCTION OF MICROAMPERE $^4He^-$ BEAMS*

Joseph John,+ C. P. Robinson, J. P. Aldridge,
W. J. Wallace, K. R. Chapman and R. H. Davis

Department of Physics
Florida State University
Tallahassee, Florida, 32306

Summary

Several modifications of the ion source of a model EN Tandem Van de Graaff Accelerator have increased the production of $^4He^-$ beams by a factor of 100 over that first obtained with the source (~10 nA). While using H_2 gas for charge exchange, the replacement of the source drift tube by a screen and the installation of a system for precise adjustment of the button alignment with respect to the extractor electrode increased the output to 150 nA at the ion source. Recently potassium vapor has been used for charge exchange. Since the introduction of this technique, $^4He^-$ beam currents of 1.2 µA have been regularly produced. The $^4He^+$ ions from a duoplasmatron ion source are accelerated to 20 keV and passed through the standard exchange canal which is modified by the addition of a potassium vapor chamber. Analyzed $^4He^{++}$ beams of 0.3 to 0.8 µA have been obtained with terminal voltage between 1.8 and 6 MV. The modified source has been used with K-vapor exchange for continuous periods of up to 120 hours without deterioration of source performance. Normal operation with H_2 gas exchange for other beams is possible without the interruption of the source operation.

Introduction

The injection of $^4He^-$ ions into a model EN Tandem Van de Graaff accelerator[1] to produce nano-ampere beams of alpha particles was reported by Carter and Davis[2] in 1961. An unmodified ion source was used in this work and hydrogen gas was the charge exchange medium. It has been possible to do a number of experiments[3] with the low intensity alpha beam, but increased beam intensities were essential to the study of reactions with low cross sections.

*Research sponsored in part by the Air Force Office of Scientific Research, Office of Aerospace Research, under Grant No. AF-AFOSR-440-67.
+On leave of absence from Bhabha Atomic Research Centre, Bombay, India.

Development work at several laboratories has led to substantial increase in the $^4He^-$ currents available for injection. This paper is a report on several simple ion source modifications which have increased the yield of $^4He^-$ beams by more than a factor of 100. The ion source now produces 1.2 to 1.5 µA of $^4He^-$ and alpha particle beam currents on target are as high as 0.8 µA. This increase has made possible the study of low yield reactions and angular correlations with alpha particles in the energy range 5 to 18 MeV.

Replacement of the Ion Source Drift Tube

In one investigation of $^3He^-$ beam production by a similar source, Middleton[4] found that the replacement of the solid drift tube which shields the beam between the last focusing lens and the exit from the ion source vacuum box by a perforated screen improved the performance of the source. The increase in output was attributed to the improved vacuum in the post exchange region, thereby markedly reducing the depletion of $^3He^-$ due to collisions with residual gas molecules. A new drift tube was made of a perforated sheet and installed. To improve the vacuum in the beam path through the 20° source magnet, an auxiliary pumping station was installed on the beam pipe immediately following the ion source vacuum box.

The installation of the screen offers the added advantage that the beam position at the exit aperture of the ion source box can be visually observed. These observations showed that small imperfections or erosion of the electrodes in or near the duoplasmatron can significantly displace the beam from the design exit position with a corresponding loss due to aperature clipping. To correct for the ion optics, a mechanism was installed for the precise alignment of the positive ion source and button assembly with respect to the extractor. Details of this device are shown in the figure. Screw adjustments on the ion source base plate determine the position of the source and button both vertically and horizontally. The result of these two modifications was to increase the $^4He^-$ output of the ion source to 150 nA.

Use of Potassium Vapor for Charge Exchange

It has been evident for some time that the use of hydrogen gas as a charge exchange medium was by no means ideal and that microampere beams of $^4He^-$ would require more than a modification of the ion source provided with the early model EN Tandem machines. The work of Donnally[5] offered a new approach to the problem. He showed that a much increased yield of $^4He^-$ could be obtained by the use of cesium vapor for charge exchange. The production of $^4He^-$ by a nearly resonant charge transfer is a maximum at a $^4He^+$ energy of about 2 keV. Using this process Rose, et al.[6] at Wisconsin have designed a system which produces 1-2 µA of $^4He^-$. The probe of an RF ion source is electrically biased with respect to the exchange chamber to obtain the proper He^+ energy. After charge exchange, the $^4He^-$ ions are accelerated and injected into the tandem accelerator. The system is attached to the duoplasmatron end of the existing system.

Donnally[7] has also suggested that potassium may be better than cesium as a charge exchange medium. It is easier to handle, should give a somewhat higher yield, and the peak yield occurs at a higher $^4He^+$ energy.

A minimum modification of the existing ion source to incorporate potassium vapor charge exchange has been made. The disturbance of the normal operating schedule of the tandem accelerator was a factor in the plan, and it was necessary to retain the source in a usable state for proton and deuteron beam production between the periods available for ion source development. The ion source assembly was unaltered except for the addition of a potassium vapor charge exchange region, immediately following the normal hydrogen exchange canal. The potassium vapor chamber was located in the expanded tubular electrode which follows the standard canal. The details are shown in the figure. This chamber is made of copper and is heated by a nichrome coil wound around it. The coil is electrically insulated from the chamber and the surrounding cylindrical electrode in which the whole assembly is mounted.

Potassium is contained in a hollow "egg" mounted below and connected to the chamber by a thick walled copper tube. This arrangement ensures that the chamber is the hottest part since heat for evaporation is conducted to the potassium via the copper tube.

Oil cooling lines to the canal region were bypassed leaving only the extractor electrode cooled. Exchange canal cooling connections are made outside the vacuum box for convenience in switching to proton and deuteron beams for which the oil cooling of the canal is necessary. Two baffles are also installed in the electrode immediately before the normal exchange canal to restrict back streaming of potassium vapor towards the duoplasmatron ion source.

The $^4He^+$ ions from the duoplasmatron ion source are accelerated to 20 kV prior to charge exchange. This appears to be the optimum voltage in the range 0-30 kV for the production of maximum analyzed alpha particle beams. The range has not been extended up to 50 kV because of the large exchange current above ~24 kV which overloads the power supply. This is primarily due to electron emission from the charge exchange regions which are not suppressed in the present design.

With these modifications, $^4He^-$ beam currents of 1.2 to 1.5 µA are regularly produced. Analyzed $^4He^{++}$ beams of 0.3 to 0.8 µA are obtained with terminal voltage between 1.8 and 6 MV. These currents are measured in the scattering chamber suitably collimated by a system of 0.050" x 0.150" slits.

The percentage transmission through the accelerator is lower than that previously obtained with hydrogen exchange and this is probably due to lower exchange voltage used with the modified source. The consumption of potassium is about 25 mg/h. In operation, the modified source is exceptionally stable, reliable, and easy to control. It has been run for continuous periods up to 120 hours without any evidence of deterioration in performance.

While almost all the work has been done on ^4He, it has been possible to obtain 800 nA of $^3He^-$ from the source with a ^3He gas flow of 35 atm-cc/h. In the first experimental use of $^3He^-$ injection, a beam of 160 nA of 18 MeV $^3He^{++}$ was measured in the beam cup of a correlation chamber. The maximum current without any restriction on ^{3}He gas consumption has not been determined.

For proton and deuteron beams it is only necessary to cease heating the oven and introduce hydrogen for charge exchange to obtain the beam currents normally available. This transition requires no interruption of source operation and can be made in a short time. The presence of traces of potassium compounds on the ceramic insulators does not seem to affect their capability to withstand the usual applied voltages.

Future Work

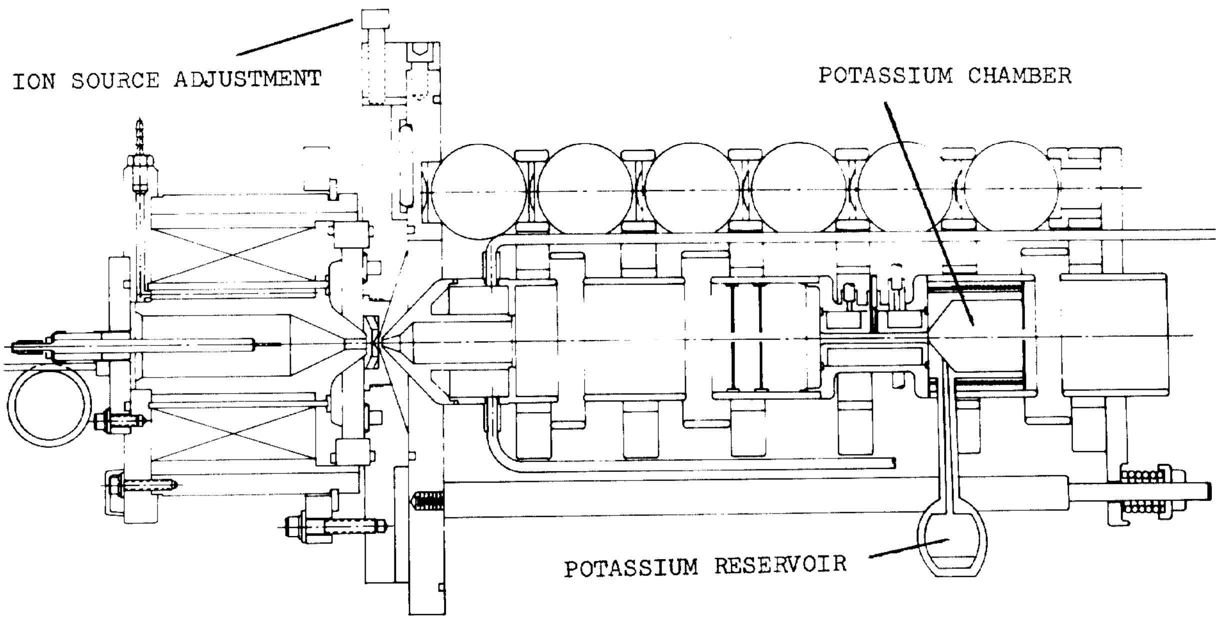
An improvement in beam transmission is needed and to achieve this, a design is being developed to allow the use of higher exchange voltages. A system for electron suppression is included and this should prevent the overload of the exchange voltage supply.

A two stage charge exchange[8], one for neutralizing the ^{4}He$^+$ ions and a second to convert the neutrals into ^{4}He$^-$ is being considered. The objective is to optimize the energy for charge exchange independent of the post exchange acceleration which is important in the transmission problem. Such a system should enable the use of potassium vapor for proton and deuteron beams as well[9].

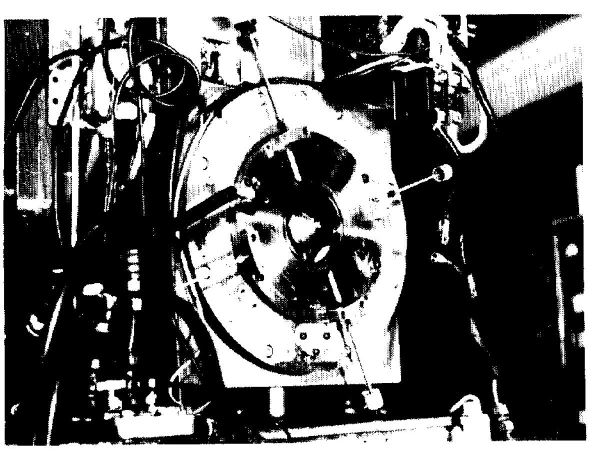
References

1. Manufactured by High Voltage Engineering Corporation, Burlington, Massachusetts.
2. E. B. Carter and R. H. Davis, Bull. Am. Phys. Soc. 6, 253 (1961); Rev. Sci. Instr. 34, 93 (1963).
3. Several of the scattering experiments are reviewed by R. H. Davis, Proc. of the Symp. on Recent Progress in Nuclear Physics with Tandems, ed. by W. Hering, (Max-Planck-Institute for Nuclear Physics, Heidelberg, 1966).
4. R. O. Middleton, private communication.
5. B. L. Donnally, unpublished.
6. Fred A. Rose, P. B. Tollefsrud and H. T. Richards, Bull. Am. Phys. Soc. 12, 29 (1967).
7. B. L. Donnally, private communication.
8. T. Cole, private communication.
9. B. L. Donnally and R. Becker, Bull. Am. Phys. Soc. 12, 29 (1967)

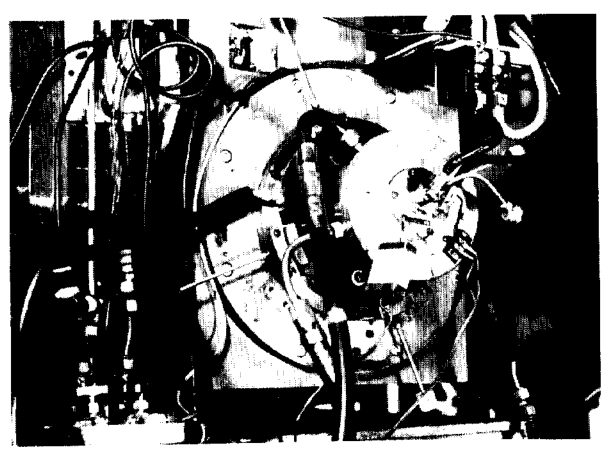
Modification of an Ion Source for the Production of Microampere $^4He^-$ Beams



Modified Ion Source Showing Button Adjustment and Potassium Exchange

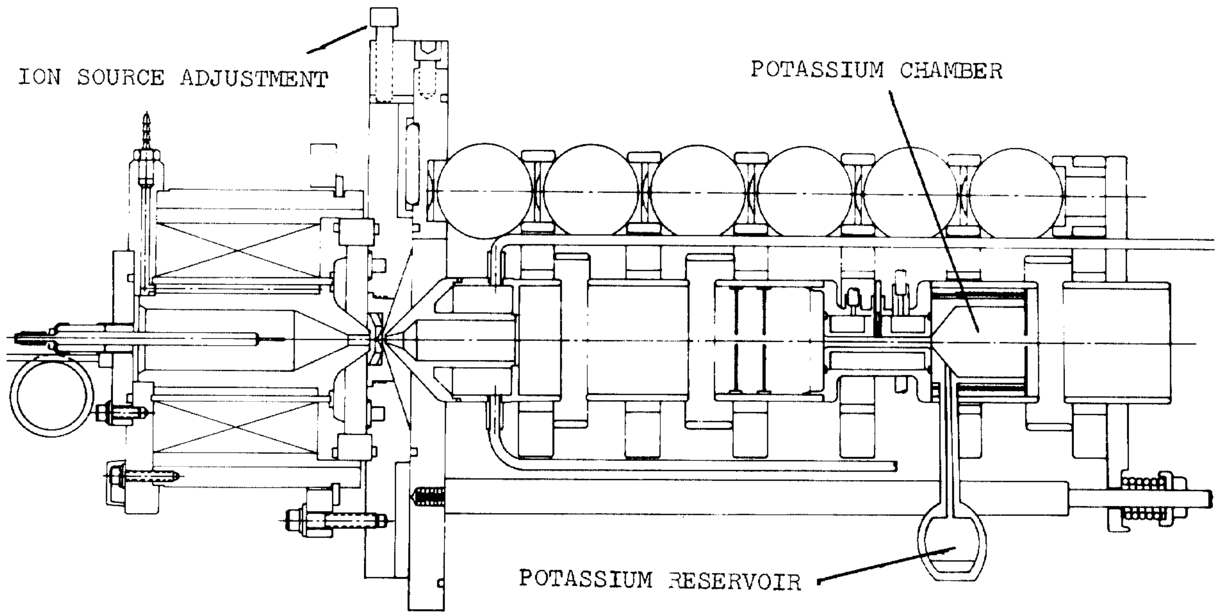


Button Adjustment Showing Guides and Mechanism

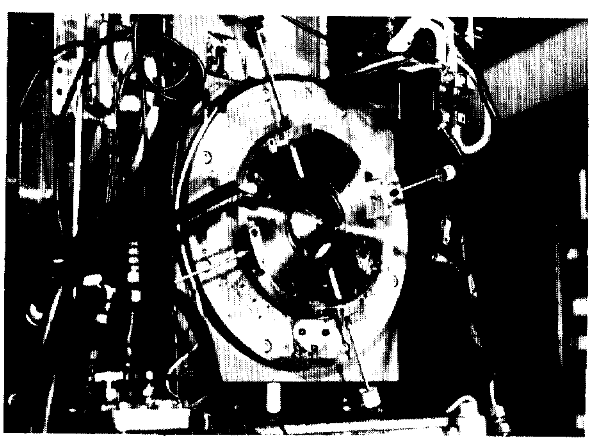


Duoplasmatron Mounted on Adjustment Mechanism

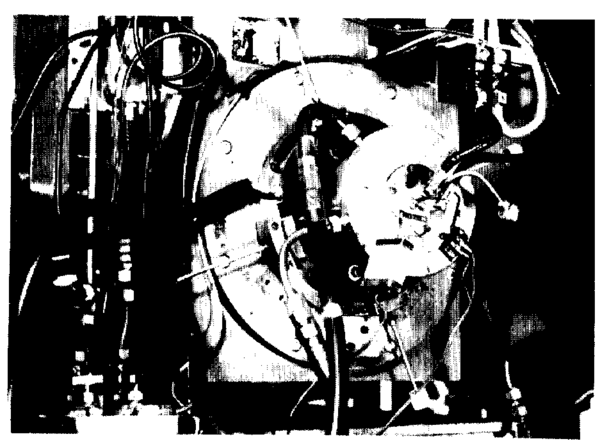
Modification of an Ion Source for the Production of Microampere $^4He^-$ Beams



Modified Ion Source Showing Button Adjustment and Potassium Exchange



Button Adjustment Showing Guides and Mechanism



Duoplasmatron Mounted on Adjustment Mechanism