Improved Performance of a He– Source

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IMPROVED PERFORMANCE OF A He^- SOURCE

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In 1966 Rose, Tollefsrud and Richards[1] developed the first source of He^- in the microamp range. Figure 1 shows the essential features of an early version of the source. An RF discharge produces He^+ ions in a quartz bottle containing helium gas at about 50 millitorr. A solenoid around the bottle produces an axial magnetic field of about 300 Gauss on axis. The field confines electrons to spiral paths enhancing the plasma density. A five kilovolt potential difference across the discharge bottle establishes near the cathode extraction canal an electrical double layer which accelerates and focusses the He^+ ions through the canal and into a charge exchange cell containing cesium vapor. For cesium vapor at the appropriate target thickness and for six-keV ions about 1.4% of the incident He^+ ions convert to He^-.

The design attempted to reduce the flow of cesium vapor and retard its buildup on electrical insulators. A baffle separated the einzel lens from the charge exchange cell. The cell itself had a narrow acceptance solid angle and was, therefore, the chief limitation on beam current. And despite the restricted geometry, cesium vapor streaming from the charge exchange canal could enter the RF bottle and ultimately cause electrical breakdown at the extraction canal.

Since that early design, many new ideas and techniques to improve performance were tested and have resulted in an almost continual evolution of the source. The first change was the removal of the einzel lens after the charge exchange region because the twenty-kilovolt gap lens alone was sufficient for good transmission through our model EN tandem accelerator. The second change involved replacing the very small charge exchange cell with a cesium vapor stream at right angles to the He^+ beam.[2]

Today's version of the source is shown in Figure 2. A diffusion pump-like stack that provided the cesium vapor stream was eventually removed in favor of the open-geometry recirculating alkali cell. In this arrangement cesium streams at right angles to the helium ion beam, condenses on the walls of the cell, and then flows back to the reservoir. A beam-heated washer between the charge exchange canal and the extractor prevents the condensed alkali metal from migrating along surfaces to the

extractor and discharge tube. Diffusion against the helium gas flow is the only remaining mechanism by which alkali vapor can enter the discharge bottle.

In 1976 we began operating with rubidium rather than cesium in the charge exchange cell. Measurements by Girnius and Anderson[3] indicated that the maximum fraction of He^- ions to He^+ ions F_- for helium incident on rubidium is larger than the maximum F_- for helium incident on cesium[4] for all energies of the He^+ beam. Table I lists the maximum fraction F_- and the He^+ energy at which it occurs for all the alkalis.

The lighter alkali vapors sodium and potassium also have large He^- yields[5,6] but require higher operating temperatures to give adequate vapor pressure and substantially higher He^+ energies, especially for sodium. Higher He^+ energy could be an advantage because in principle a larger space charge limited beam current is possible. But our experience is that operation with more than about six kilovolts across the discharge bottle leads to electrical breakdown near the extractor, large return electron currents to the anode, and accelerated sputtering of the extraction canal. Even for five-keV He^+ beams the return electron current deposits as much as forty watts on the anode. The tantalum electron stop keeps the Viton O-ring from overheating.

We find either cesium or rubidium easier to handle than the other alkali metals because they melt at relatively low temperatures and can be poured into the loading port after filling the source with dry argon. Adequate vapor pressure of rubidium occurs with temperatures of 260°C at the reservoir and 135°C on the walls of the exchange region. Air cooling suffices to remove the modest amount of power supplied to the source.

Figure 3 shows a comparison of the present quartz bottle and extractor geometry to that in use until 1975. In the early design on the left a pair of quartz discs cemented to the inside of the quartz tube shielded the outer surface of the extractor. This shielding forces the plasma double layer to form in front of the opening in the extractor. But because the available quartz tubes are not round, one could not ensure alignment of the hole in the quartz discs with the extraction electrode (which was clamped independently to the baseplate). We also had problems with sparking through the zirconium-base cement. The cement was tedious to apply and required a thorough bake out before a new bottle could be used on the source.

The design on the right eliminated these problems. We now fuse vacuum tight a quartz disc to the end of the tube. A sleave of boron nitride fits between the extractor and the quartz disc and is positively aligned even if the tube is out of round. The boron nitride also serves as the inner ring for a Viton O-ring.

Sputtering of the iron extraction canals in use until recently

limited lifetime to about 100 hours. Sputtered material coats the quartz tube reducing the RF power available to ionize helium and also alters the potential in the region of the extractor. The notch between the two quartz discs and the complicated shape of the extractor on the left were attempts to retard the onset of electrical breakdown caused by the build-up of conducting material inside the quartz disc. These modifications helped only slightly, however, and we now use the simpler construction shown on the right.

Previous experience had indicated that the use of a ferromagnetic extractor increases the yield of He^+ from the source, presumably by increasing the magnetic flux and hence the plasma density in the immediate vicinity of the extractor tip. We were reluctant, therefore, to use a nonferrous extractor. Recently we tested other cathode materials in search of one that sputters less readily than iron. With either molybdenum or graphite we obtained the same beam current and emittance as we had with iron extractors. The molybdenum extractor sputtered rapidly and blackened the quartz tube in only a few hours. But a graphite cathode eroded much less than either molybdenum or iron. The rate of percentage mass loss for graphite was eight times less than for iron.

The most recent work on the source was a redesign of the RF shielding and the addition of a potentiometric controller to maintain the 260°C temperature of the rubidium reservoir independent of line voltage fluctuations. Temperature control had been impossible previously because of RF interference. The new shielding also permitted reliable emittance measurements for the first time. Our emittance measuring device[7] continuously scans and measures both the phase space area and the portion of the total beam current within a given brightness contour. Figure 4 shows the results of several different measurements of the He^+ and He^- beam emittance as a function of the percent of total beam current included. The shape of an emittance versus percent-of-beam curve resembles one of the solid curves. For He^+ beams the emittance curves lie between the upper and lower curves. The He^- emittance lies between the upper and middle curves.

Scattering in the charge exchange region is relatively unimportant, producing only a slight increase in the average emittance of He^- beams compared to He^+ beams. We have tested the source with three different alkali vapors-rubidium, cesium, and potassium-and find no dependence of the He^- emittance on which alkali vapor is used for charge exchange.

Table II lists typical operating and performance parameters for the He^- source. We now routinely obtain six microamps of He^- current, the record being 14.5 microamps. With the temperature controller maintaining the 260°C reservoir temperature, we adjust the flow of cooling air to obtain 135°C in the exchange region. Too much cooling freezes rubidium in the exchange canal and stops its recirculation. The pressure of 50 millitorr is an estimate based upon flow considerations. The best indication of proper helium pressure (and also of purity) is the blue-green color of the discharge. We use a liquid nitrogen cooled trap on the gas inlet to remove most contaminants from the helium supply. Good performance results for very pure helium gas at as low a pressure as possible without extinguishing the discharge. A ten gram charge of rubidium is sufficient for more than 200 hours of continuous operation.

References

1. F.A. Rose, P.B. Tollefsrud and H.T. Richards, IEEE Trans. Nucl. Sci. NS-14 No. 3 (1967) 78.

2. H.T. Richards, Proceedings of the Symposium on Ion Sources and Formation of Ion Beams, BNL 50301 (Upton, N.Y. 1971) 295.

3. R.J. Girnius and L.W. Anderson, Nucl. Instrum. & Meth. 137 (1976) 373.

4. A.S. Schlachter, D.H. Loyd, P.J. Bjorkholm, L.W. Anderson and W. Haeberli, Phys. Rev. 174 (1968) 201.

5. B.A. D´yachkov and V.I. Zinenko, Sov. Phys.-Tech. Phys. 16 (1971) 305.

6. R.M. Ennis, Jr., D.E. Schechter, G. Thoeming, D.B. Schlafke and B. Donnally, IEEE Trans. Nucl. Sci. NS14 (1967) 75.

7. L.L. Ames, Nucl. Instrum. & Meth. 151 (1978) 363.

Table I

MAXIMUM CONVERSION FRACTION F_- FOR He^+ INCIDENT ON ALKALI VAPORS

Alkali	Max. F_- (%)	He^+ Energy (keV)	Reference
Li	0.6	12	D'yachkov & Zinenko (1971)
Na	1.7	12	D'yachkov & Zinenko (1971)
K	1.7	7.5	Ennis et al. (1967)
Rb	1.7	7	Girnius & Anderson (1976)
Cs	1.4	6	Schlachter et al. (1968)

Table II

TYPICAL He^- SOURCE PARAMETERS

Oscillator Voltage	800 V
Current	260 mA
Extractor Voltage	5 kV
Current	8 mA
Axial Magnetic Field	300 G
Gap Voltage	20 kV
Rb Charge	10 g
Rb Reservoir Temperature	260 °C
Exchange Canal Temperature	135 °C
Pressure	50 mTorr
Total Power Consumption	400 W
Operating Life	> 200 h
He^- Current	6 μA
He^- Emittance (85%)	6.5 π mm mrad $MeV^{1/2}$
He^- Beam Energy	25 keV

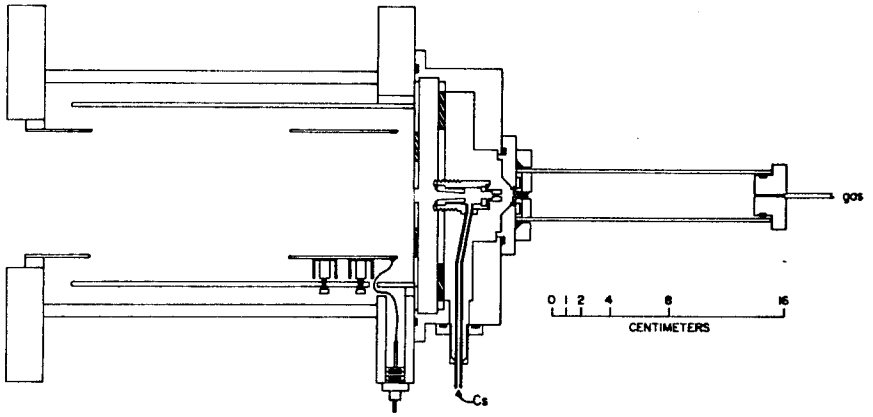

Figure 1

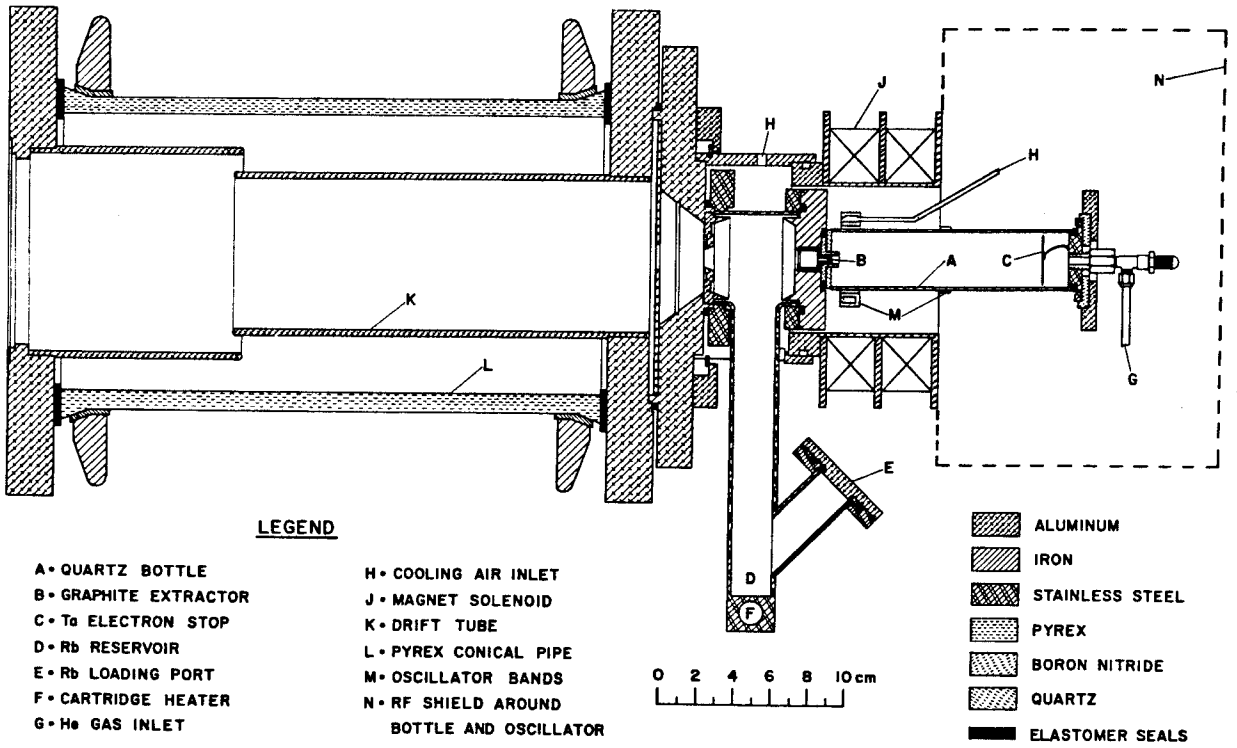

Figure 2

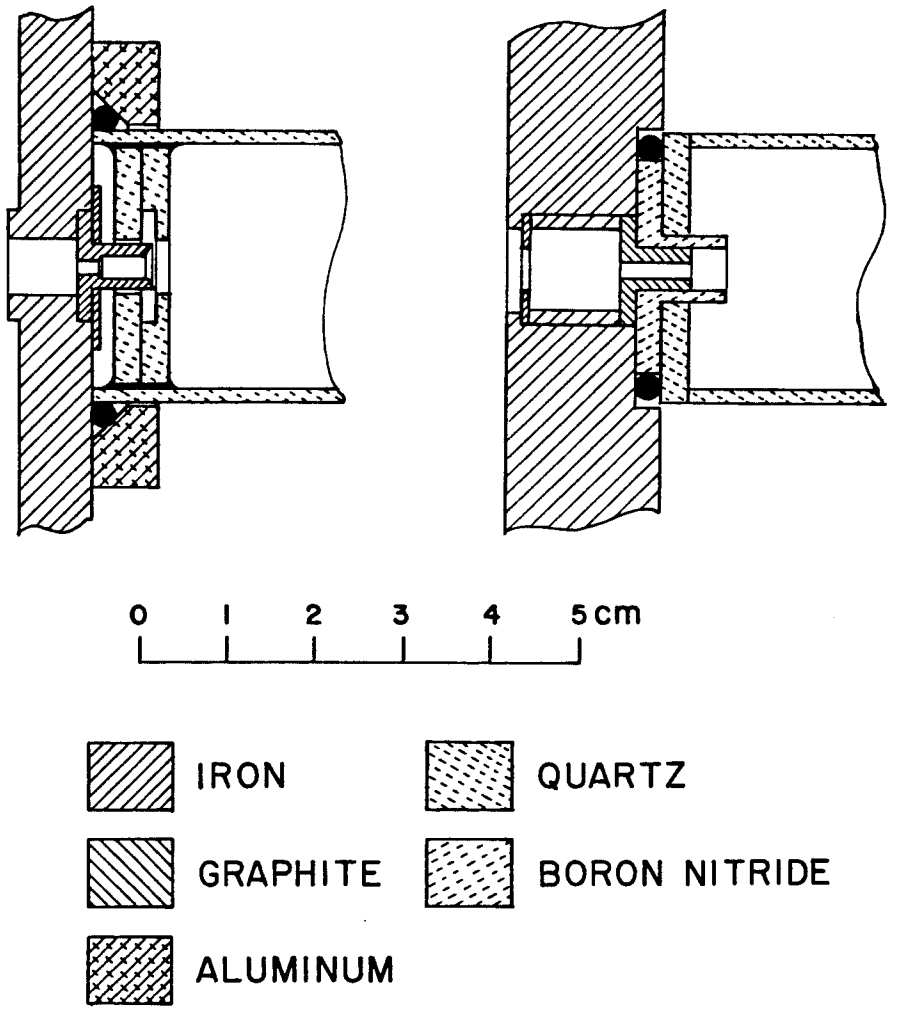

Figure 3

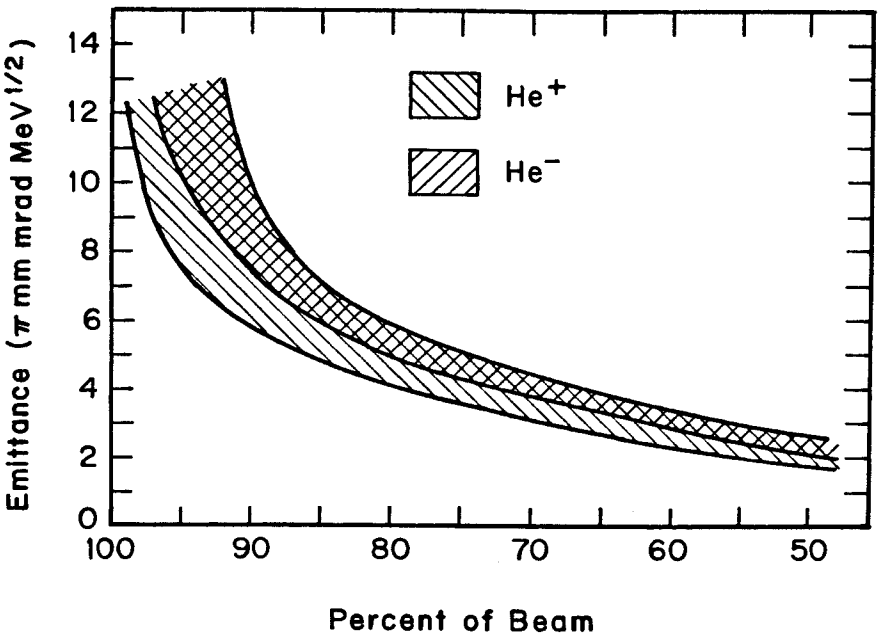

Figure 4