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Production of Negative Helium ions

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A negativ helium ion source using potassium charge exchange vapor has been developed to be used as an injector for the Pelletron accelerator[1]. ^3He and a bem currents of up to 2μA have been extracted with 75% particle transmission through the machine.

Uma fonte de íons negativos de hélio utilizando vapor de potássio para troca de carga foi desenvolvida para ser utilizada junto com o Acelerador Pelletron . Feixes de partículas de ^3He e a, com intensidade entre 1 e 2 μA são extraídos. Uma transmissão de 75% das partículas através do acelerador é conseguida

1. INTRODUCTION

Two-stage particle accelerators require the injection of negative ions. In the case of helium, due to the electronic configuration and the small affinity of an extra electron, very low efficiency is obtained in the formation of a negative ion.

The design of the negative helium ion source, to be used together with the Pelletron accelerator of the University of São Paulo, was based on the two step process of forming He^- ions and on the required optical characteristics of the beam.

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2. PRODUCTION OF He^-

Holφien and Midtdal[2] showed that the $(1s\ 2s\ 2p)^4\ ^4P_{5/2}$ state of He^- is rnetastable with an estimated[3] mean life of 1.7×10^{-3} sec. In this $^4P_{5/2}$ state, the binding energy of the $2p$ electron is of the order of 0.075 eV, Ref. 4, and all the other possible states of He^- undergo decay by auto-ionization, i.e., decay by emission of a free electron.

Based on this argument, Donnally *et al.*[5] suggested that negative helium ions could be produced by a nearly-resonant two-step charge exchange reaction, as follows:

(i) Forrnation of He^0 $(1s\ 2s)\ ^3S_1$ from He^+ $(1s)$ by a charge exchange transfer collision with an alkali atom;

(ii) Forrnation of He^- from He^0 $(1s\ 2s)\ ^3S_1$ by pick-up of a $2p$ electron:

$$He^+ (1s) + X^0 \rightarrow He\ (1s\ 2s)\ ^3S_1 + X^+ \quad \text{and}$$

$$He^0\ (1s\ 2s)\ ^3S_1 + X^0 \rightarrow He^-\ (1s\ 2s\ 2p)\ ^4P_{5/2} + X^+.$$

Charge exchange reactions are nearly-resonant when the change $|\Delta E|$ of the interna1 energy of the colliding system is very small. A qualitative interpretation of this feature may be given in terms ofthe extent to which the collision approximates to adiabatic conditions. This fact is a consequence of the "Massey criterion"[6] which states that the cross-section for a charge exchange reaction is maximum when the collision time is of the order of the electronic transition time.

Calculations based on this criterion[7] and further experimental results[5,8] indicate that, in the case of a He^+ primary beam, a satisfactory efficiency can be reached when an alkali element (vapor) is used as the medium for the charge transfer.

In Table 1 are shown the calculated[7] resonance energy for the two individual pick-up reactions, i.e., formation of the He^0-atom and He^- ion. As both reactions occur in the same chamber they are not obser-

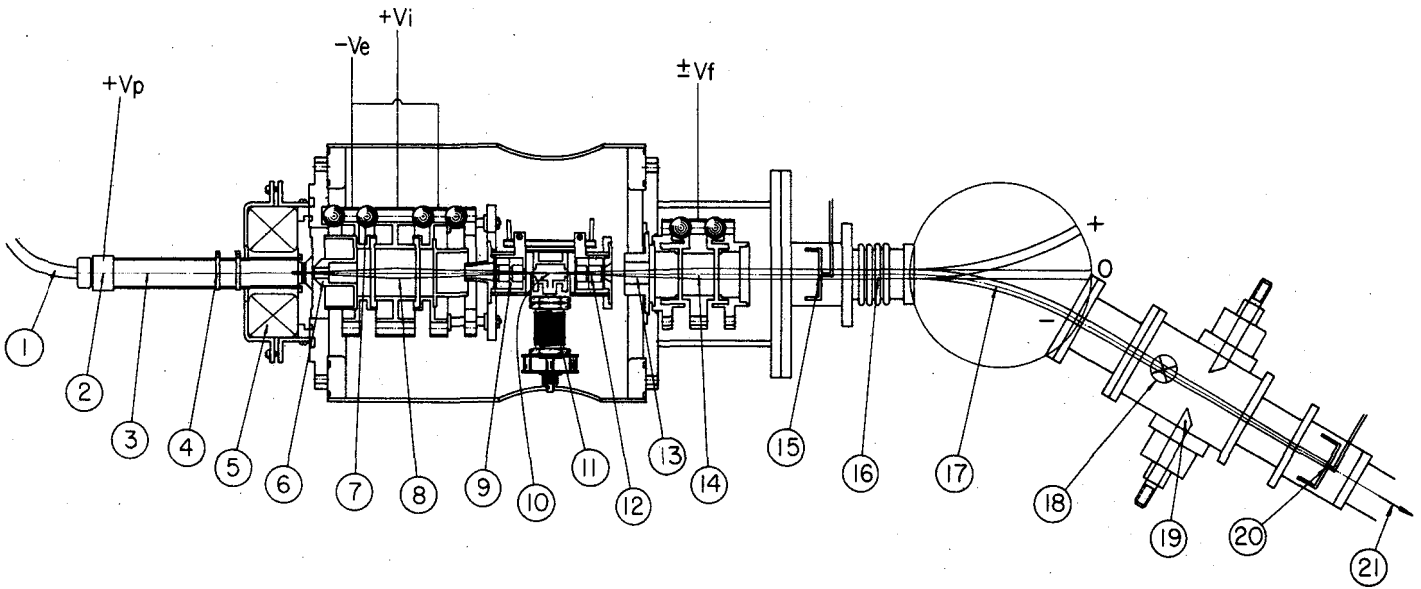

Fig. 1. The negative ion source:
1- gas imput; 2- probe (V_p); 3- R.F. bottle; 4- Capacitive R.F. coupling; 5- magnet; 6- extraction electrode; 7- insulator; 8- einzel lens; 9- entrance diaphragms; 10- Charge exchange chamber; 11- oven; 12- exit diaphragms; 13- gap lens; 14- second einzel lens; 15- Faraday cup; 16- magnetic analyser; 17- air inlet; 18- slits; 19- Faraday cup.

ved individually, and the experimental resonance energy for the complete process is shown in the last column of Table 1.

Table I. Resonance energy (KeV) for:

Element	1st step: individual formation of $(1s2s)^3S_1$ He^0	2nd step: individual formation of $(1s2s2p)$ $^4P_{5/2}$ He^-	Experimental
Li	0.16	87.4	~30 (Ref.10)
Na	0.14	34.8	
K	0.17	29.7	~11 (Refs.7, 10,11)
Cs	0.58	9.0	~ 5 (Ref. 9)

Among the alkali elements, potassium seems to be the more convenient because it has the necessary vapor pressure[12] at low temperature (~140°C), is easier to handle, cheaper, and less toxic.

3. THE APPARATUS

The negative helium ion source (Fig. 1) consists essentially of a conventional R.F. positive helium ion source[13] (Fig. 1:3) from which He^+ ions are extracted when a positive bias V_p is applied (Fig. 1:2). An extraction electrode (Fig.1:6) together with an einzel lens (Fig.1:8) is used to focus the positive beam in the charge exchange chamber (Fig. 1:10). This chamber is filled with the alkali vapor obtained by heating the potassium in a stainless steel oven (Fig.1:11). The exchange chamber is electrically connected to the external electrodes of the einzel lens. In this way, it is possible to control the He^+ beam energy so as to maximize the efficiency of the charge exchange process. A very small contact area between the chamber and its support reduces the heat loss.

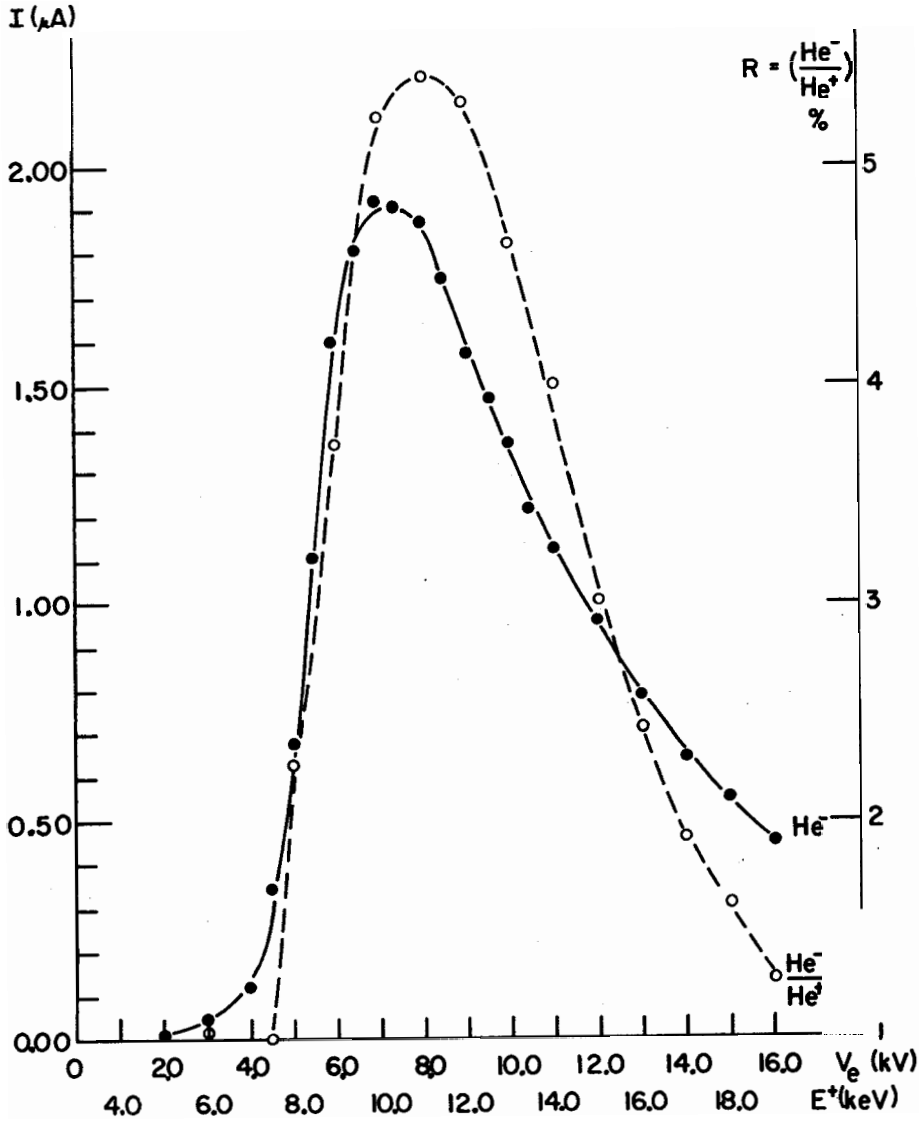

Fig. 2. He^-/He^+ yield and beam intensity vs. He^+ energy.

To prevent the condensation of potassium in the high electrical gradient region of the ion source, two pairs of copper diaphragms are used in the entrance (Fig.1:9) and exit (Fig.1:10) of the charge exchange chamber. To increase the efficiency of trapping of potassium vapor, the diaphragms are cooled by a freon exchanger circuit[14].

A second einzel lens (Fig.1:14) is used in the He^- beam transport. A magnetic analyser (Fig. 1:17) is employed to separate the different components of the beam, mainly He^0, He^+ ions, contaminants and electrons. In this case, a 30^o deflection is used, defined by a slit system (Fig.1:19).

The negative helium ions are then accelerated up to an energy of 85 KeV by means of a ten electrode accelerating tube. This final beam energy was chosen to get the largest possible overlap between the emittance[15] of the ion source and the acceptance of the Pelletron accelerator.

Thus a satisfactory particle transmission through the machine can be obtained.

4. CHARACTERISTICS AND PERFOMANCE OF THE ION SOURCE

As the charge exchange process is nearly-resonant, there exists an optimum energy at which the efficiency is maximum. In Fig. 2, one can see the dependence on the incident energy of the yield (i.e the ratio He^-/He^+ beam intensities). A maximum ratio of 5% can be reached at a collision energy of 11 KeV. This result is in agreement with the limits predicated by the Massey criterion.

The total He^- beam intensity as a function of He^+ energy is also presented in Fig. 2. One can see that the energy corresponding to the highest beam intensity does not correspond to the highest ratio He^-/He^+. This is due to the fact that the charge exchange chamber bias is the same as the extraction electrode bias which affects the extracted He^+ beam intensity.

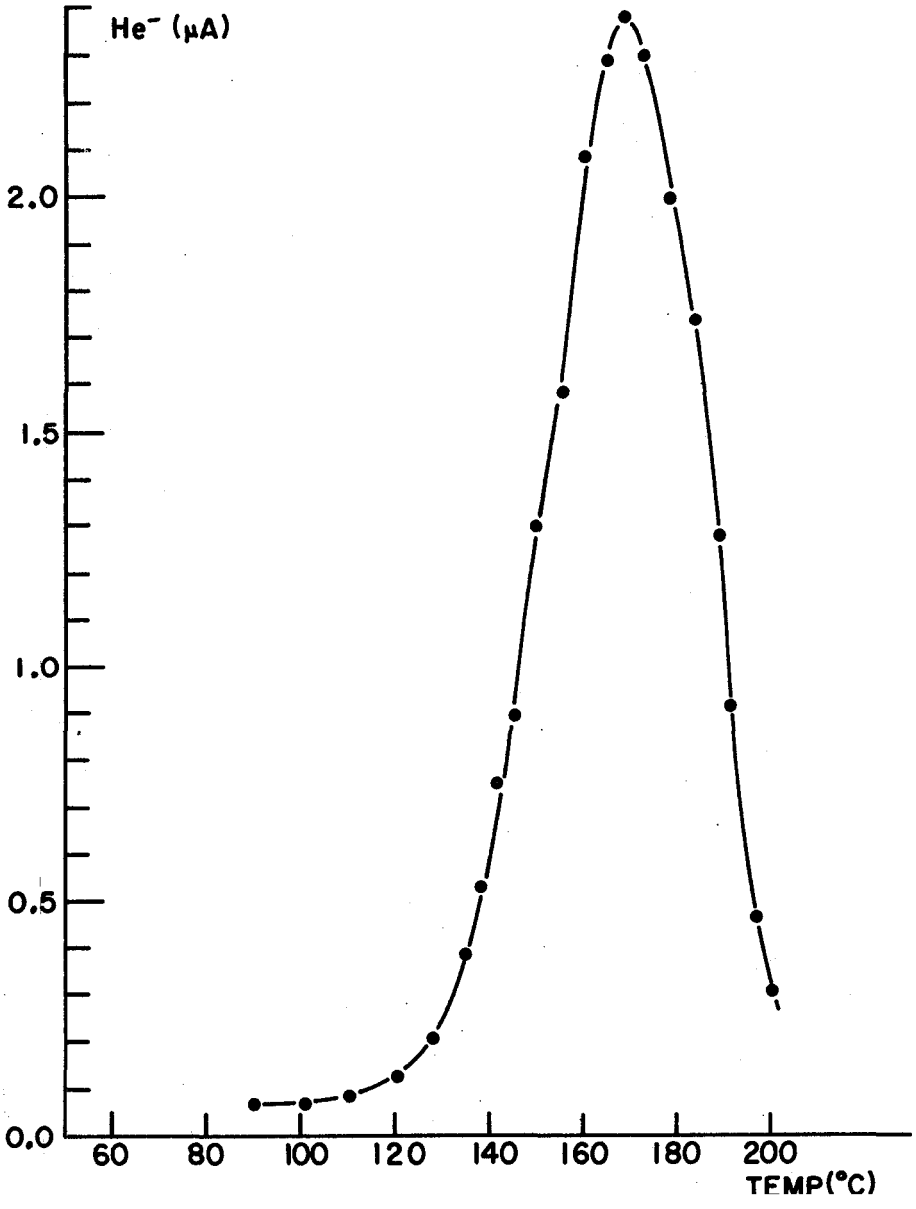

Fig. 3; He^- beam intensity vs. potassium temperature.

The dimensions of the charge exchange chamber allow a 95% positive beam transmission. Negative helium beam intensities of the order of 1-2 μA can be reached, depending on the operation conditions.

The potassium vapor pressure inside the charge exchange cell is very critical; with a very low pressure, two collisions of the He^+ ion during its transit in the cell are improbable; and with a high pressure there is a large probability of losing the $2p$ electron (which is very weakly bound to the He^- atom: 0.075 eV).

The potassium vapor pressure is controlled by the oven heating current. The oven and cell temperatures are monitored by means of an iron-constantan thermocouple.

The relation between the negative beam current and the temperature of the potassium container is shown in Figure 3. The potassium consumption is estimated in 100 mg per hour.

It is found necessary to process the potassium before use in the ion source. The oven is heated out of the source, in vacuum, until the potassium melts and all the oil bubbles out.

In normal operation, a good vacuum ($\sim 10^{-6}$ Torr) is required inside the source. A change of 50% in this pressure can be responsible for a reduction of 20% in the He^- beam intensity.

The ion source described in this article has been in normal operation in the Pelletron Accelerator of the University of São Paulo since 1973, for the injection of $^3He^-$ and $^4He^-$ beams.

A particle transmission of 75% for ^3He and a beams is normally obtained

The ion source is able to operate during a continuous period of one week. When the potassium in the oven is exhausted, the container can be replaced easily without dismounting the ion source.

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