Investigation of an Intense H- Ion Beam
Produced by a Volume Source.

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Abstract

An H- ion beam from a volume source is accelerated to 20 keV and transported 86 cm in a region where the pressure was varied in the range 10^{-6} to 7×10^{-4} Torr. The accelerator was operated under *low* and *high pumping* conditions. The diagnostics used were a combined Faraday cup/calorimeter and a pinhole profile analyzer. We found that the exponential dependence of the unstripped H- current on pressure in the transport region was not valid under *high pumping*. This is explained by the presence of a significant neutral fraction with beam energy at the accelerator exit. A theoretical analysis is proposed for determining not only the correct value of the negative ion current, but also the values of the positive ion and neutral beam components. The profile measurements established that at low pressure in the transport region the H- beam expands due to its space charge and that the electrons produced by stripping concentrate on a ring at the periphery of the negative ion beam. The neutral component of the beam was also determined by using the pinhole analyzer as a secondary electron detector.

I. INTRODUCTION

The H- volume ion source and the accelerator built and tested by Dammertz and Piosczyk[1], have been transferred to Ecole Polytechnique and installed on a test stand equipped with a large pumping capability (40,000 l/s) provided by a titanium evaporation pump[2]. A hydrogen negative ion beam produced by a tandem volume source is accelerated to voltages in the range 10 to 20 kV and transported 86 cm in a region where the pressure can be varied in the range 10^{-6} to 7×10^{-4} Torr. The charged particle beam current is measured using a Faraday cup, FC, while the total beam current is determined by calorimetry using the same Faraday cup as a calorimeter. A pinhole profile analyzer, located at the same distance from the source, was also used[2]. Assuming that no current from the beam plasma reaches the FC, the current to FC represents the difference between the currents of beam negative ions and beam positive ions :

$$I_{FC} = I(H^-) - I(H^+) \qquad (1)$$

The *calorimetric* current value represents the full beam current, including both the charged and neutral particles, with the assumption that they have the full energy :

$$I_{cal} = I(H^-) + I(H^+) + I(H^\circ) \qquad (2)$$

The extraction aperture diameter used in this work is 0.65 cm. Two different versions of the source pumping through the accelerator were studied, designated as *low* (6 l/s) and *high* (~15 l/s).

II. EFFECT OF ATOMIC COLLISIONS INDUCED BY THE BEAM ON I- MEASUREMENT.

As a beam of particles all in the same charge state passes through a gas target, charge states different from the initial one are formed during the collisions. In the case of an H- ion beam passing through the accelerator and transport region containing a background pressure molecules and atoms, the main collision processes leading to formation of neutral atoms, H°, and positive ions, H+ (see Refs. 3,4), are single electron detachment (stripping) from H- and H°, double electron detachment from H-, electron capture from H+ and H°, double electron capture from H+.

The operation of the volume H- ion source is associated with some dissociation of the molecular gas. Measurements of the atomic hydrogen fraction in similar sources[5] indicated that this fraction does not exceed 10% of the density of H_2 molecules. Thus stripping of H- in collisions with H atoms may be important for low H- ion energy (E≤5 keV) where σ_{-10} for atoms is considerably larger than for molecules[4].

All the energetic particles can ionize the background gas[6,7]. This reaction is very important for the beam transport because it provides the necessary positive particles inside the beam to neutralize the space charge and therefore allows the beam to be transported without much spreading.

We have solved three coupled differential equations for the beam fractions F-, F+ and F° considering a purely molecular hydrogen target. A relevant parameter to characterize the beam entering the transport region is:

$$\alpha = F^- / (F^- + F^\circ) \qquad (3)$$

We present on Fig. 1 the results obtained with two different initial conditions for the beam entering the target: (a) a pure H- beam ($\alpha=1$); (b) a beam composed of equal parts of H- and full energy H° ($\alpha=0.5$). The length of the transport region is 86 cm.

Fig 2 shows the dependence of F--F+ calculated with various fractions α ($0<\alpha<1$) in the beam entering the gas target. This plot can be compared to the experimental I_{FC}/I_{cal}, taking into account Eqs. 1 and 2.
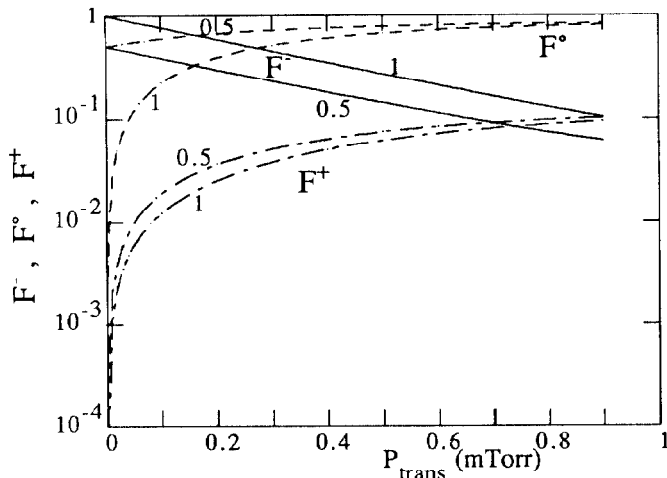
Fig. 1: Variation with H_2 pressure in the transport region of the H^-, H^+ and H° fractions, F^-, F^+ and F°. These fractions are obtained by solving a system of three coupled differential equations. Acceleration energy: 15 keV.
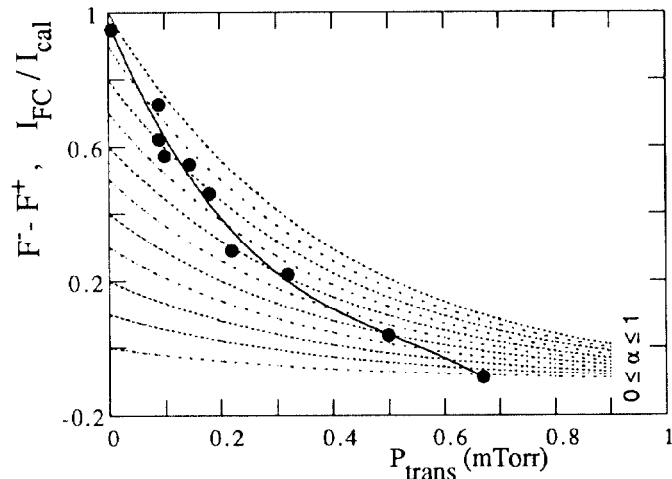

Fig. 2: Variation with the pressure in the transport region of F^--F^+ from theory (dotted lines), with α values from 1 to 0, and from experiment, I_{FC}/I_{cal} (full circles), in the *high pumping* configuration. Acceleration energy: 15 keV.

We compare on Fig. 3 the theoretical unstripped fraction of the H^- ion beam, when $\alpha=1$, with the experimentally determined I_{FC}/I_{cal}, for different pressures in the transport region. This is justified only when $I(H^+)$ is much less than $I(H^-)$ (see Eq. 1). We found an agreement in the case of the *low pumping* configuration, but not in the *high pumping* case, when we observed more stripping and the current changing sign at much lower pressure than predicted by theory, with $\alpha=1$. The reason of this discrepancy seems to be the presence in the beam entering the transport region of a fraction of full beam energy neutrals, produced by stripping in the last section of the accelerator. In this, *high pumping* configuration, the pressure gradient in the accelerator is dependent on the pressure in the transport region. Therefore in this case the neutral fraction at the accelerator exit is dependent on the pressure in the transport region. In the *low pumping* configuration of the accelerator the stripping inside the

accelerator is only weakly dependent on the pressure of the transport region.
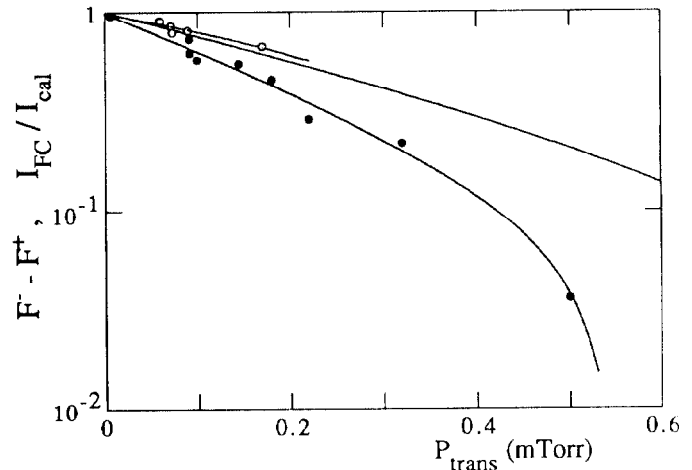

Fig. 3: Comparison of measured I_{FC}/I_{cal} with the theoretical value F^--F^+, for $\alpha=1$. Open circles: *low pumping* configuration; full circles: *high pumping* configuration. Extraction aperture diameter: 0.65 cm. Acceleration energy: 15 keV.

Fig. 2 compares the experimental data I_{FC}/I_{cal} in the *high pumping* configuration with the theoretical predictions for F^--F^+ with various values of α. The experimental curve crosses the theoretical curves: when the pressure in the transport region is enhanced the experimental values fit calculations with decreasing values of α. This confirms the hypothesis that the neutral fraction at the exit of the accelerator is dependent on the pressure in the transport region. Thus at each pressure in the transport region we identify the corresponding α. It appears that at 0.5 mTorr the experimental data are consistent with $F^--F^+=0.04$, much less than it would be if a pure beam of negative ions would exit from the accelerator ($F^--F^+=0.21$); the corresponding value for α is 0.4.
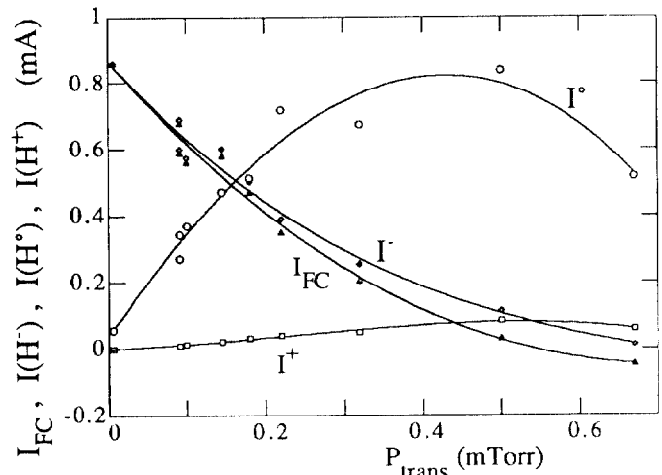

Fig. 4: Variation with pressure in the transport region of true I^-, I° and I^+ deduced from experiments with the combined FC/calorimeter. *High pumping* configuration. The measured current on FC is also shown.

2012

With the known α the array of theoretical curves shown on Fig. 1 allows the determination of F^- at the FC. Since $I^-=F^-\times I_{cal}$, we can determine I^-. In a similar way we can find I^+ and I°; they are plotted on Fig. 4. If the results are plotted in terms of π (target thickness), one can determine F^-, F^+ and F° in any point of the transport region

When the pressure in the transport region is enhanced, the current to FC goes down, due to H^- stripping; the produced slow electrons do not reach the FC collector, because of the negatively biased suppressor[2]. A large fraction of these electrons attain the front electrode of FC (a ring with an internal diameter 2.5 cm and an external diameter 9.6 cm). The interpretation of this finding is that the slow electrons produced by stripping (and possibly ionization) concentrate on a ring at the beam periphery. We also found an easy way of eliminating these electrons from the negative ion beam, by surrounding the beam by a suitably biased ring electrode.

III. INVESTIGATION OF BEAM PROFILE.

The beam profile analyzer consists of three electrodes: the first one, containing a pinhole aperture (1 mm in diameter), is followed by a secondary electron suppression electrode and a collector. The beam profile analyzer was operated in three different regimes, to monitor:

a) The charged particle beam profile: the suppressor is biased negative with respect to the first electrode and to the collector, to prevent secondary electrons from leaving these electrodes. A negative ion profile is shown on Fig. 5. It was observed that at low pressure in the transport region (4×10^{-6} Torr), the negative ion beam expands due to its space charge (FWHM is 1.3 cm, instead of 0.9 cm at 4×10^{-6} Torr).

b) The profile of all negative particles: the collector is biased positively, so that the field it produces penetrates into the space between the suppressor electrode and the first electrode. Therefore it collects all the negative particles entering the analyzer. Typically the first electrode is biased at +30 V, the suppressor at -30 V and the collector at +50 V. Fig. 5 shows also the profile of all the negative particles (negative ions and electrons). Note the presence of two electron peaks located symmetrically on both sides of the H^- peak. We attribute these peaks to the slow electrons produced by stripping and ionization along the beam line, which concentrate on a ring around the beam. The pressure effect confirms this explanation.

c) The charged and neutral beam particle profile: the secondary electrons emitted from the collector are collected on the suppressor (which is biased positive with respect to the collector). In this case the first plate is at +30 V, the suppressor is at +15 V and the collector is at ground potential. From this measurement we isolated the profile of the beam neutrals. The estimate of the neutral component by this method agrees with the measurements described in Sec. II with the combined Faraday cup/calorimeter.
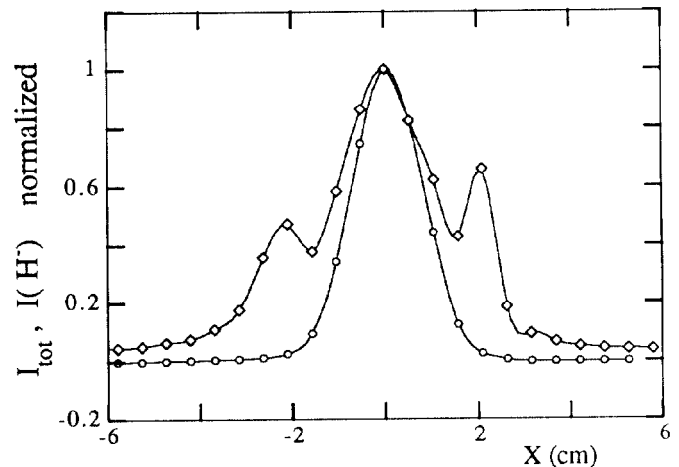

Fig. 5: Comparison of the beam charged particle and all negative profiles.

IV. CONCLUSION

1) Low Energy Beam Transport is complicated because of two oppositely acting effects: space charge expansion, at low transport region pressure, and stripping, at high pressure, when the beam negative space charge is neutralized.

2) The electrons produced by stripping concentrate on a ring at the periphery of the beam. They can be eliminated using a suitably designed ring electrode.

3) When the accelerator conductance is increased between the source and the transport region, the pressure gradient in the accelerator is dependent on the pressure in the transport region. Due to this, a significant full energy neutral fraction can be produced at the accelerator exit, which affect the charged particle beam current.

4) Under *high pumping* conditions the unstripped negative ion beam may not follow an exponential dependence on the pressure in the transport region. We propose a method for calculating the correct beam fractions in any point of the transport region.

V. REFERENCES

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