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129

DEVELOPING A 500-eV PROTON BEAM

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ABSTRACT

Tests have been carried out which indicate that H^- intensity limitations in Lamb-shift polarized ion sources result from large divergence in the 500-eV H^+ ion beam. Intensity limitations due to other effects are not yet measurable.

INTRODUCTION

Discussions during the 1981 Polarized Source Workshop were almost uniformly directed toward the topic of increased beam intensity. Most interest centered around new sources. However, because of the large investment (both money and time) many laboratories have in Lamb-shift (LS) sources, it seemed pertinent to examine the future of this type source.

The limitation of a LS source is simple to describe:

Several cross section measurements of $H^+ + Cs \rightarrow H^0(2s) + Cs^+$ and $H^0(2s) + Ar \rightarrow H^- + Ar^+$ and efficiency measurements of the state selection process have been carried out.¹⁻⁶ Calculations based on these results indicate that a LS source should produce on the order of 1-2 μA H^- per hyperfine state for each 1 mA H^+ injected into the Cs canal. While duoplasmatrons can easily produce 20 mA H^+ , Lamb-shift sources are still struggling at the 1 μA per hyperfine state intensity level.

A plan was outlined by the 1981 LS working group⁹ to determine why LS sources do not produce at least 10 μA at 80% polarization. There were two major questions to be answered:

1. Do space charge forces within the 500 eV H^+ beam result in excessive divergence?
2. Are $H^0(2s)$ atoms quenched by the ions in the beam?

The remainder of this report summarizes the initial answers to these questions. While several interesting (and possibly contributing) phenomena are reported, few definitive conclusions can yet be drawn.

LAMPF has supported the research effort required on this project by providing both a test stand and additional personnel. The test stand consists of the metastable beam formation portion of the complete ion source shown in Figure 1. Protons are extracted from the duoplasmatron and formed into a 500 eV beam using an accel-decel lens system. $H^0(2s)$ (metastable) atoms can be generated by charge exchange in the cesium cell and polarized by state selection in the spin filter.

SPACE CHARGE EFFECTS:THEORY

Calculations indicate that the H^+ beam entering the cesium cell must be space charge neutralized. One argument for this requirement follows: If $H^0(2s)$ atoms are to be converted to H^- ions in the argon cell, their trajectories at the instant of $H^+ \rightarrow H^0(2s)$ conversion in the cesium cell must lie within the solid angle subtended by the argon cell entrance. Calculations show⁸ that with no space charge neutralization, only 0.37% of a 3 mm diameter 1 mA H^+ beam can produce $H^0(2s)$ within the proper solid angle.

A second argument involves destruction of the $H^0(2s)$ thru quenching. The space charge potential of a uniform density non-neutralized beam may be calculated as:

$$V = \frac{I}{4\pi \epsilon_0 c} \frac{v}{\beta} = \frac{I * 29.97\Omega}{\beta}$$

For a 1 mA 500 eV ($\beta=0.00103$) proton beam, $V=29.0$ volts.

The electric field strength is given by:

$$E = \frac{\lambda}{2\pi \epsilon_0 \beta c r} = \frac{I * 59.95\Omega/m}{\beta r}$$

where λ = charge per unit beam length. For a uniformly distributed 3 mm diameter H^+ beam, the maximum electric field is 388 volts/cm. Under these conditions, over half the $H^0(2s)$ formed in this field will decay before travelling 1 cm.

SPACE CHARGE EFFECTS:EXPERIMENT

Initial tests were carried out on the ion source prior to construction of the test stand. Figure 2 shows the physical arrangement used for the first test. A 0.178 mm diameter tungsten filament was placed in tension on the cesium cell axis. A Lyman-alpha (L_α) detector was positioned adjacent to the sight hole in the cesium cell wall to detect any radiation resulting from quenching. The proton beam intensity at the entrance to the cesium cell was 1.25 mA $\pm 10\%$.

When the beam tests were begun, it was found that the two 1.52 mm diameter filament supports (oriented perpendicular to one other) intercepted 90% of the beam normally available under similar source operating conditions. This indicates that the beam must have a diameter of approximately 3 mm.

The column faraday cup (item #12 in Figure 1) was used to measure both the unpolarized H^+ ion intensity resulting from two electron pickup in the cesium cell and polarized H^+ ion currents. Figure 3 shows normalized faraday cup currents and normalized L_α signal level as a function of filament current. While the intensity improvements were encouraging, three factors could modify the results under normal operating conditions:

1. The H^+ beam was low intensity in this test.
2. The filament supports intercepted 90% of the beam.
3. The radiant heat from the tungsten filament necessitated extensive cooldown periods between data points.

Factors 2) and 3) prompted the filament redesign shown in Figure 4. It was shortened to 25 mm length, increased to 0.38 mm diameter and moved outside the cesium cell. Both ends were electrically isolated so that a bias voltage could be applied. A helix was placed around the filament to retain the coaxial arrangement. The filament/helix assembly was mounted on a three axis manipulator so that position sensitivity tests could be made. The helix was later found to be unnecessary.

H^+ space charge neutralization (SCN) measurements were made by transporting 500 eV beam from the decel electrode to the column faraday cup. The cesium cell was removed for the initial tests. The 36.5 mm diameter exit aperture of the argon cell defined the beam transmission solid angle (4.65×10^{-4} sr). With the SCN filament off and grounded, a calculated maximum H^+ current of 1.47 μA should have reached the cup. Only 0.70 μA was measured. With the filament current and bias optimized (10A and 6V), the measured current increased to 250 μA , a gain of over 350. This was achieved with 7.5 mA H^+ coming thru the decel lens aperture. These results remained essentially unchanged as the filament was moved radially ± 1.25 mm about the beam axis.

The cesium cell was then reinstalled, charged and allowed to cool to 30°C. The cell temperature was then slowly increased to raise the cesium vapor density. At low densities, the filament continued to provide increased beam intensity. However, as the cesium density became significant, the beneficial effect of the filament rapidly dwindled. When the density was at normal operating conditions, the filament effect was small enough that no significant improvement could be claimed. This indicated that the cesium was probably neutralizing the beam as effectively as the filament.

At this density, the H^+ intensity in the column cup was 60 μA with the filament off and grounded. The focus lens polarity was then reversed and the H^- beam intensity was also found to be 60 μA .

The test results can be summarized as follows:

1. With the filament providing SCN, 250 μA of 500 eV H^+ ions can be delivered 1.5 m into the proper solid angle. This is, however, only 3.3% of the measured beam intensity exiting the decel electrode.
2. With cesium present at the optimum level, 120 μA (total charged particles) lies within the same solid angle. The neutral intensity ($H^0(1s)$ and $H^0(2s)$) was not measured but certainly could comprise a major fraction of the missing

- 130 μ A. But, at least to within a factor of two, cesium provides SCN as efficiently as does the filament.
3. This source normally produces 250 nA H^- . With 250 μ A usable H^+ available, this would imply overall $H^+ + H^-$ efficiency of 0.1% , close to the expected value.

500 eV H^+ BEAM STUDIES

Based on the above results, it appears that the low intensity H^- problem might be solved by having a higher brightness H^+ beam. Therefore, a series of tests have been carried out on the test stand to determine the divergence and degree of neutralization of the H^+ beam. To determine the bulk H^+ beam properties, the SCN filament (Figure 4) was replaced with a shielded e^- suppressed faraday cup. The decel electrode was also instrumented to detect particle impingement. Of 20 mA extracted from the duoplasmatron, 12 mA hit the decel electrode and 8 mA went into the faraday cup. Careful measurements were made of all pertinent parameters for use in SNOW⁹ calculations. One result of those calculations is shown in Figure 5. The beam divergence is obvious.

A Langmuir probe was then constructed to measure the depth of the potential well within the beam. With the SCN filament reinstalled but deenergized, the beam potential immediately downstream of the decel electrode was 13 ± 1 volts. The beam divergence was great enough to preclude any meaningful measurements. With the filament energized, however, the potential was reduced to 3.5 ± 0.3 volts. It was measured at four axial locations. The results are shown in Figure 6.

The probe was then used to measure the beam spatial distribution at various axial locations. The distribution was found to be approximately gaussian in shape. The divergence was evaluated from the intensity FWHM as a function of axial position. The FWHM points diverged at 3 degrees.

A "harp" has now been installed on the test stand to provide a real time display of the H^+ beam distribution. The harp consists of 0.076 mm. diameter tungsten wires spaced 1.0 mm apart. Each of the 16 wires has its own integrating preamplifier. The preamplifier outputs are scanned by a multiplexer to produce the oscilloscope trace shown in Figure 7. The harp assembly can be moved along the beam axis, simplifying beam divergence measurements.

FUTURE PLANS

One attempt has been made to focus the neutralized H^+ beam with a magnetic lens. The results were encouraging and further tests and development will be carried out.

To date, no redesign of the H^+ beam formation region has been attempted. The goal in such work would be to:

1. Reduce the beam divergence.
2. Improve transmission through the decel electrode.

We do not yet understand the reduction in L_a signal shown in Figure 3. Further tests are planned to determine the mechanism involved.

The authors wish to thank O.B. van Dyck and J.R. Bilskie for providing an operational harp multiplexer system. Their work made our job much easier.

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FIGURE 1.
Section view of the LAMPF Lamb-shift
polarized source.

FIGURE 2.
L_α detector, cesium cell, and filament
arrangement used in early space charge
neutralization tests.

FIGURE 3
 Normalized La and column faraday cup (H^- and H^+)
 signal strengths as a function of filament
 current. H^+ current is 1.25mA.

FIGURE 4
Redesigned space charge neutralization
test arrangement.

FIGURE 5
SNOW Output Plots for 20mA Beam

FIGURE 6

Potential of Neutralized 500eV
Beam at 4 Axial Locations

FIGURE 7
Sample Harp Output