Effective transportation of negative hydrogen ions in a synthesized hydrogen beam

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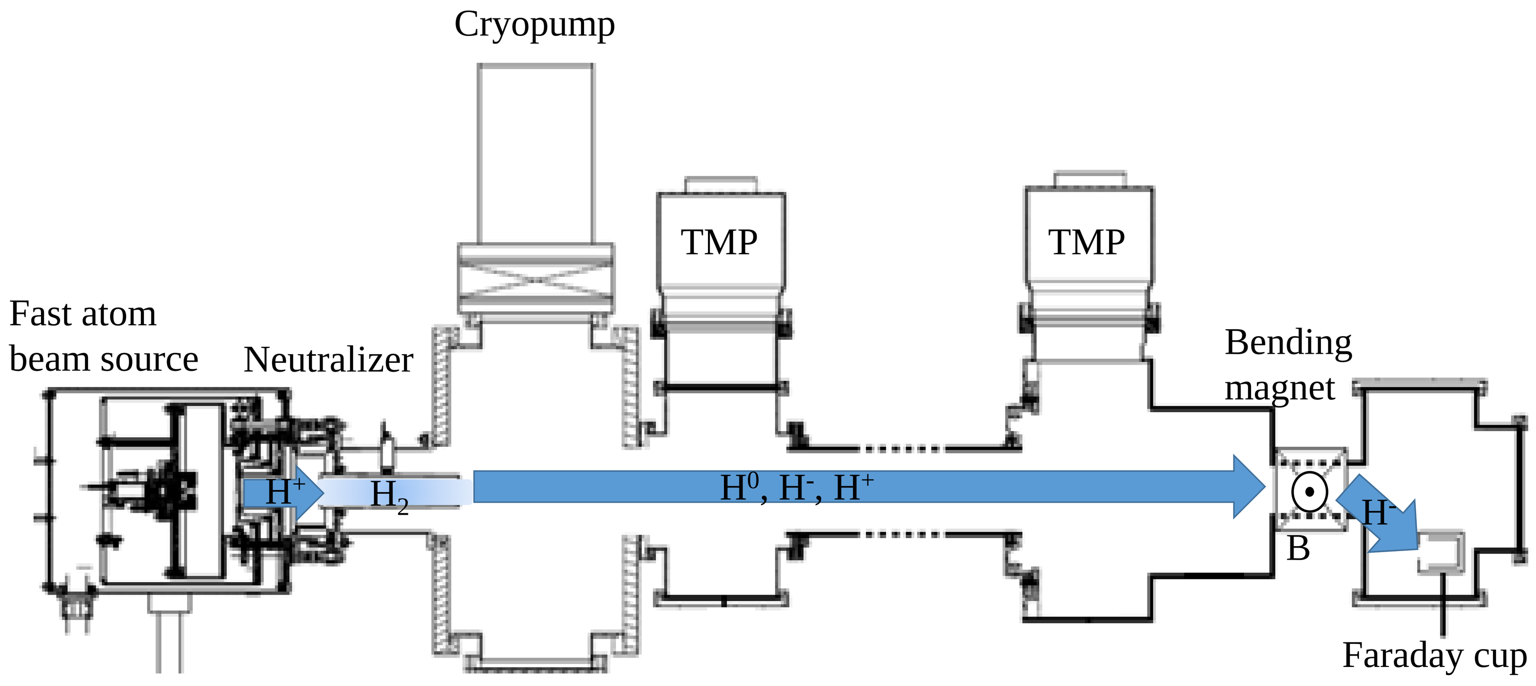
Effective transportation of negative hydrogen ions formed during charge exchange of a high-brightness proton beam with ballistic focusing in a hydrogen charge-exchange target was observed in experiment. A beam of protons with an energy of 10 keV, a current of 4.7 A, an emission current density of 470 mA/cm^2, an angular divergence of 10 mrad, and a focal length of 200 cm was formed at 1 Hz frequency in the fast atom beam source of the polarized ion source OPPIS at BNL. The measured value of H^- ion current passing through a 2 cm diaphragm located at a distance of 200 cm from the emitter was 75 mA. This value is much higher than that explained by atomic beam ballistics. The effective negative hydrogen ion beam transportation is based on interaction of charged particles and positive plasma potential of the synthesized charge-exchanged beam of hydrogen particles. An H^- ion yield weakly depends on beam energy, while total primary proton current is strongly increased at higher energy. Therefore, it is expected at 20-30 keV beam energy it is possible to produce a few hundred mA of the H^- ion beam intensity (in Cesium-free source), which might be used for some accelerator applications.

TEST STAND

A proton beam formed by a source of fast atoms (FABS) enters the charge-exchange target of the neutralizer, where a significant part (~ 90%) is converted into atoms. Passing through the pumping system and the drift space, the beam get into the bending electromagnet, installed at a distance of 200 cm from the source, and, further, into the Faraday cup.



FABS parameters:

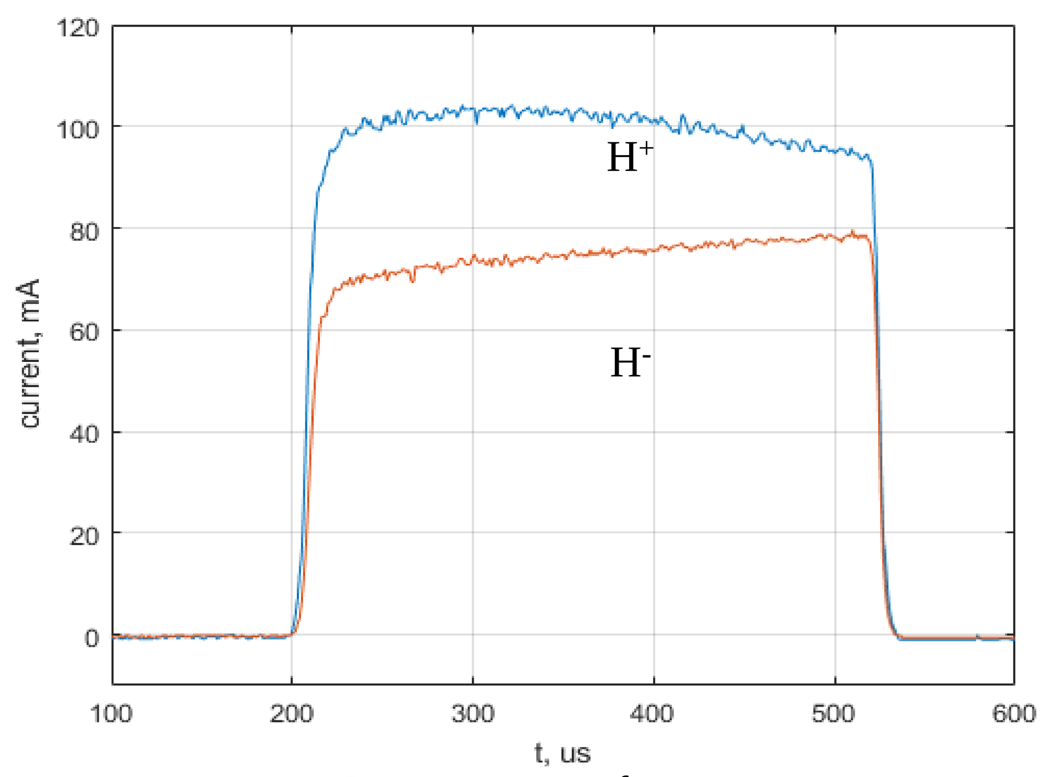
• Beam energy	5-10 keV
• Beam current	2.5-4.7 A
• Emitter current density	250-470 mA/cm^2
• Divergence	10 mrad
• Focal length	200 cm
• Pulse length	500 µs
• Repetition rate	1 Hz

ION CURRENT MEASUREMENT

Ion currents were measured after bending magnet using Faraday cup with a diaphragm 2cm in diameter at 200 cm from FABS.

Beam parameters:

• Energy	10 keV
• Current	4.7 A
• Emission density	470 mA/cm^2



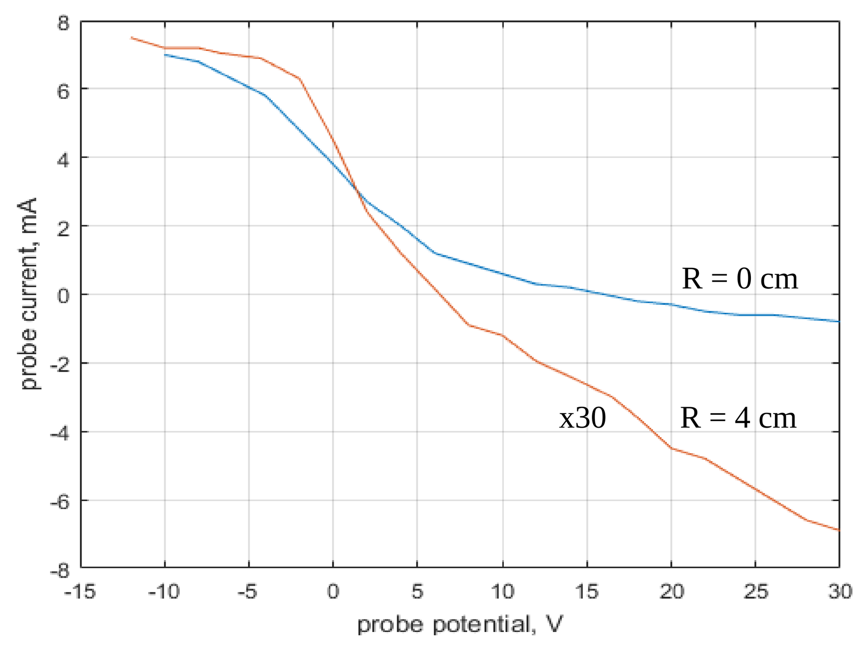
Ion currents waveforms

	Ion current from hydrogen target(yield)	Measured ion current
H^+	94 mA (2%)	75 mA
H^-	470 mA (10%)	100 mA

The measured value of the ion current H^- is 75 mA, and 100 mA of the proton current, so the ratio of the local density of negative ions to positive ions on the beam axis increases significantly when moving away from the ion-optical system by 200 cm. This phenomenon can be explained by the presence of a positive potential on the beam axis with a value of several volts, which arises from insufficient compensation of the space charge of the beam by thermal electrons.

BEAM POTENTIAL

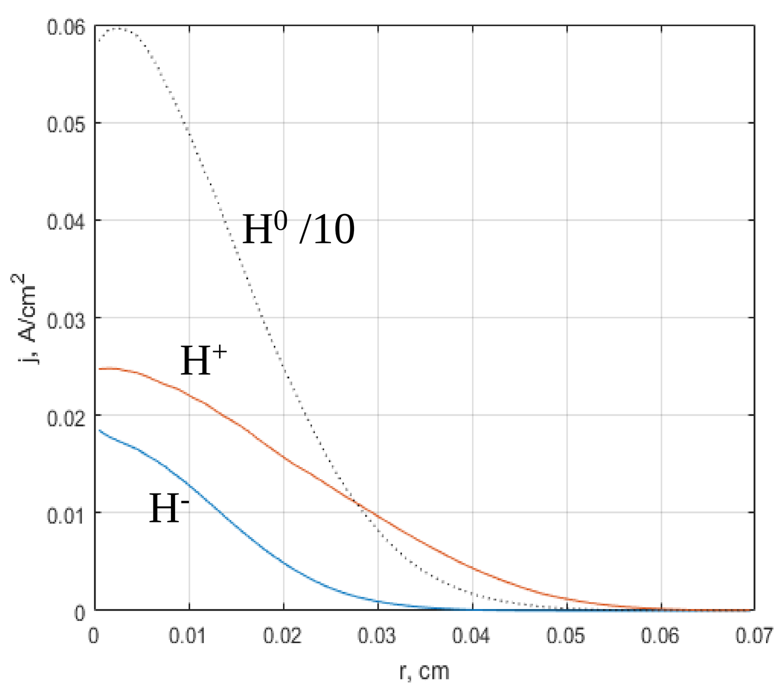
Measurements of the current-voltage characteristics of the Langmuir probe in plasma of the synthesized beam were made. The measurements were carried out at a distance of 140 cm from the ion-optical system on the beam axis and at a radius of 4 cm.



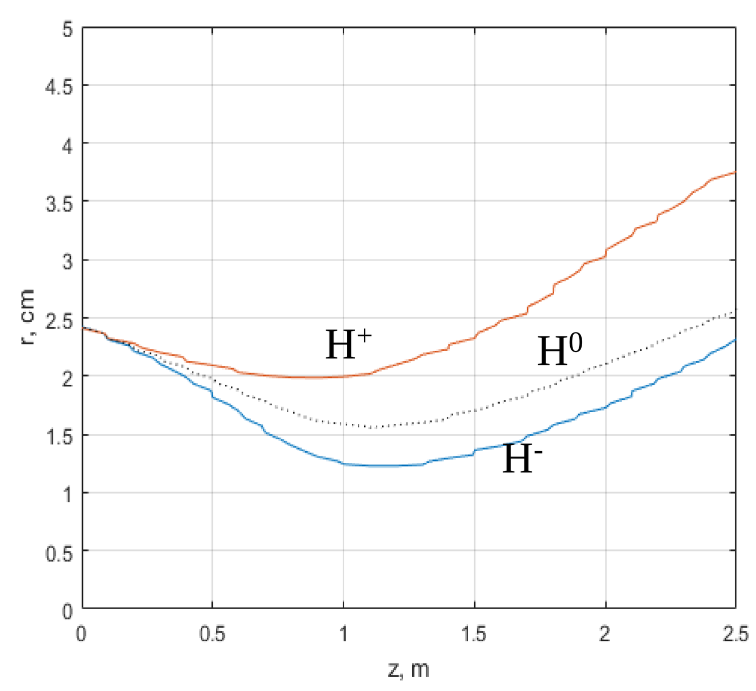
Volt-ampere characteristics of the Langmuir probe

It can be seen that at positive probe voltages the relative probe current at a 4 cm radius is much larger and increases with the voltage, this is explained by the presence of electrons in the beam. On the beam axis, the relative current at positive voltages is much smaller and depends weakly on the voltage, which indicates a small fraction of the electrons in the beam. The potential of the beam plasma, determined from the maximum of the derivative of the current-voltage characteristic in both cases, is ~ 2 V.

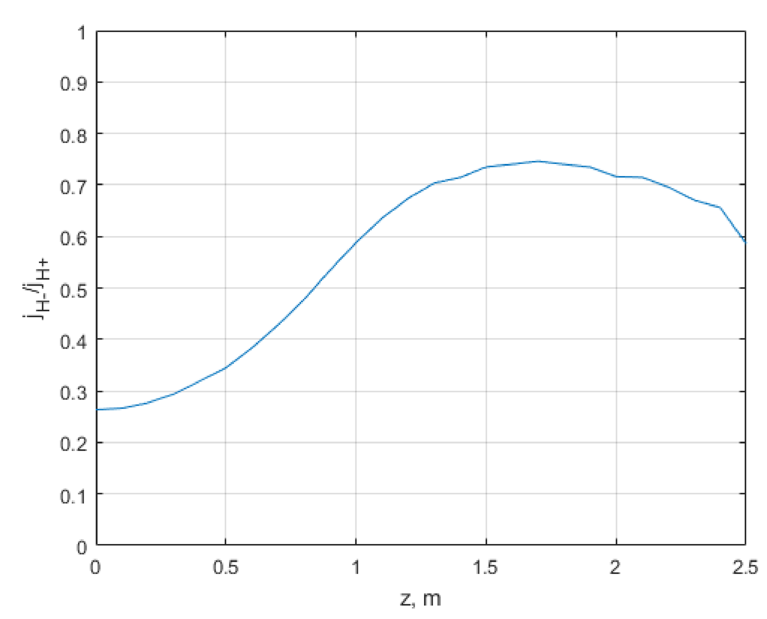
NUMERICAL SIMULATION



Beam fractions profiles



Envelopes at 1/e level



Proton density to H^- density ratio profile

CONCLUSION

As a result of measurements, the focusing of negative ions in the positive potential of the synthesized hydrogen beam was observed and studied. The 10 keV beam energy was limited by available power supply. An energy dependence of the H^- ion beam yield drops to 1.8% at 20 keV (and 1.4% at 30 keV). The primary proton beam current strongly increases with the beam energy (from 3,2 A at 8.0 keV to 4.7 A at 10 keV). And H^- ion beam current increases from 50 to 75 mA. Therefore, it is expected at 20-30 keV beam energy it is possible to produce a few hundred mA of the H^- ion beam intensity (in Cesium-free source). The H^- beam emittance is similar or smaller than neutral hydrogen beam emittance, which is estimated ≤0.5 π·mm·mrad. This phenomenon can be used to obtain intense beams of negative ions for accelerator applications. The use of an ion source without the use of alkali metals can significantly increase the reliability and durability of the installation.

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