Creating Nitrogen Beams in an Alphatross™ Ion Source for Injection into a Tandem Accelerator

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Abstract

Over the past 15 years, Hope College has been creating hydrogen and helium ion beams with an Alphatross™ ion source and Pelletron™ tandem Van de Graaff accelerator. The manufacturer stated the possibility of creating nitrogen ions in this source, but Hope College has not, up until now, attempted to do so. By mixing approximately 1% nitrogen into hydrogen source gas, nitrogen (N^-) and imidogen (NH^-) ions are created and accelerated through the tandem accelerator. These ion beams are directed and isolated by a dipole bending magnet for identification. Alternate beams such as these open up new possibilities for future experiments such as nitrogen implantation.

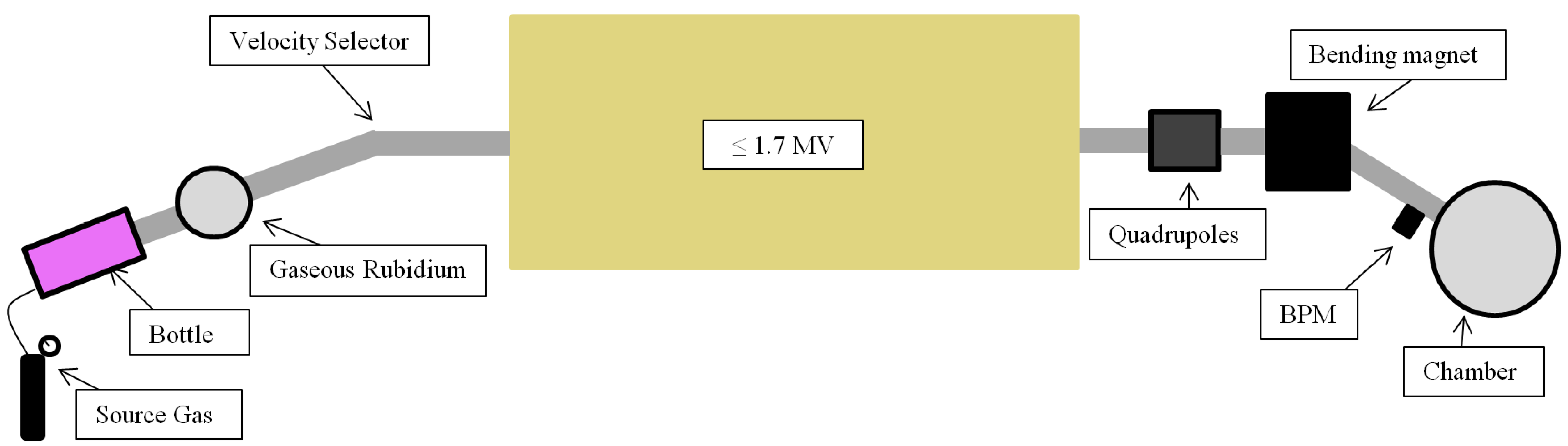

Figure 1: Simplified schematic of Hope College's Alphatross™ Ion Source and Pelletron™ tandem Van de Graff accelerator.

Ion-Source

The Alphatross™ Ion source first ionizes the source gas by exciting the particles with a magnet and an oscillating electric field. Then, a probe voltage of 3.0 kV repels the positive ions out of the bottle, where they go through gaseous rubidium. They then take electrons from the rubidium in order to emerge as negative ions. Finally, the velocity selector bends the particles using a variable electric field in order that they are in line with the next process, the tandem accelerator. This velocity selector is the first major tuning aid which affects particles of various masses differently. Thus, it is necessary to optimize the velocity selector settings for these alternate beams.

High Energy

In the tandem accelerator, the negative ions are pulled toward the high voltage terminal, where some of the electrons are stripped off through an interaction with nitrogen gas. Since this converts them back to positive ions, they then are repelled away from the high voltage towards the final stage. After leaving the terminal, the beam is bent by a dipole bending magnet towards a detection chamber.

Description	Setting
Probe	3.0 ± 0.1 kV
Bias	10.28 kV
Velocity Selector	0.56 ± 0.02 kV
Current in Dipole Magnet	40.0 ± 0.1 A

Figure 2: Best-found settings for N^{1+} of N^- at a terminal voltage of 1.2 MV.

Dipole Bending Magnet

In order to predict the necessary magnetic field in the bending magnet, first sum the forces:

$$\sum F = q \cdot v \cdot B = m \cdot \frac{v^2}{r}$$

By cancelling a v and using $mv = \sqrt{2mE}$:

$$B = \frac{\sqrt{2mE}}{qr}$$

where r is the radius of the particle's path. It is then evident that the necessary current in the magnet (which is proportional to the magnetic field) is:

$$I_2 = I_1 \cdot \frac{q_1}{q_2} \cdot \sqrt{\frac{E_2}{E_1} \cdot \frac{m_2}{m_1}}$$

From this ratio, it is easily seen that the current is proportional to $\sqrt{E \cdot \frac{m}{q^2}}$. Thus, we used this along with an offset (to account for uncontrollable offsets in the system) as a mathematical model for fitting our data.

Results

After calculating and implementing expected magnet settings and adjusting the velocity selector, the nitrogen beams were found. N^{2+}, N^{3+}, and various ions of oxygen were also observed. In addition, some of the observed nitrogen originated not as N^- after the gaseous rubidium but as NH^-. The data was fitted well by the expected mathematical model.

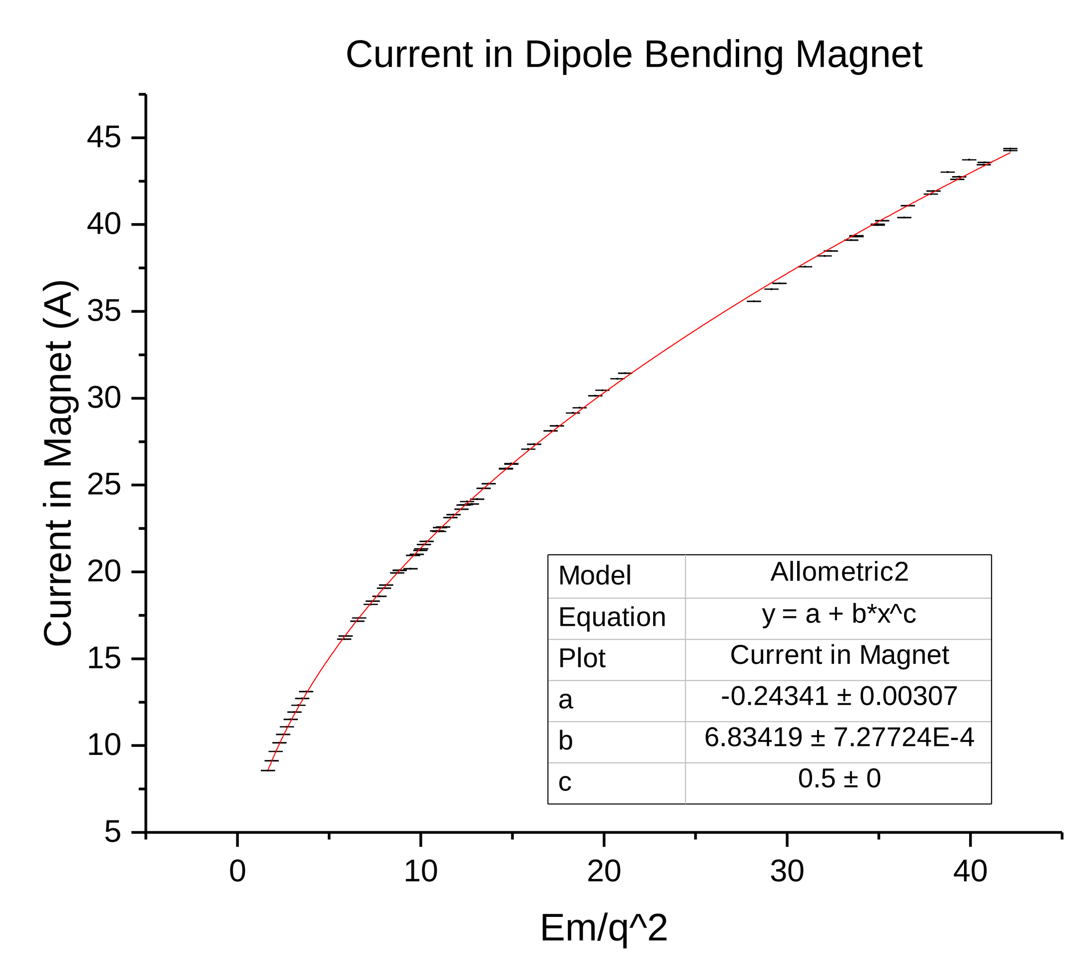

Figure 4: For any particle with a given energy, mass, and charge, the current required to bend it increases according to the mathematical model.

Uncertainty & Hysteresis

Uncertainty for the current in the bending magnet originates primarily because the faraday cup reading dithers and makes it difficult to determine the current that produces that maximum beam.

Hysteresis made some measurements difficult to take. When a large electromagnet strongly magnetizes the core, the current must be decreased more than expected to arrive at the desired magnetic field.

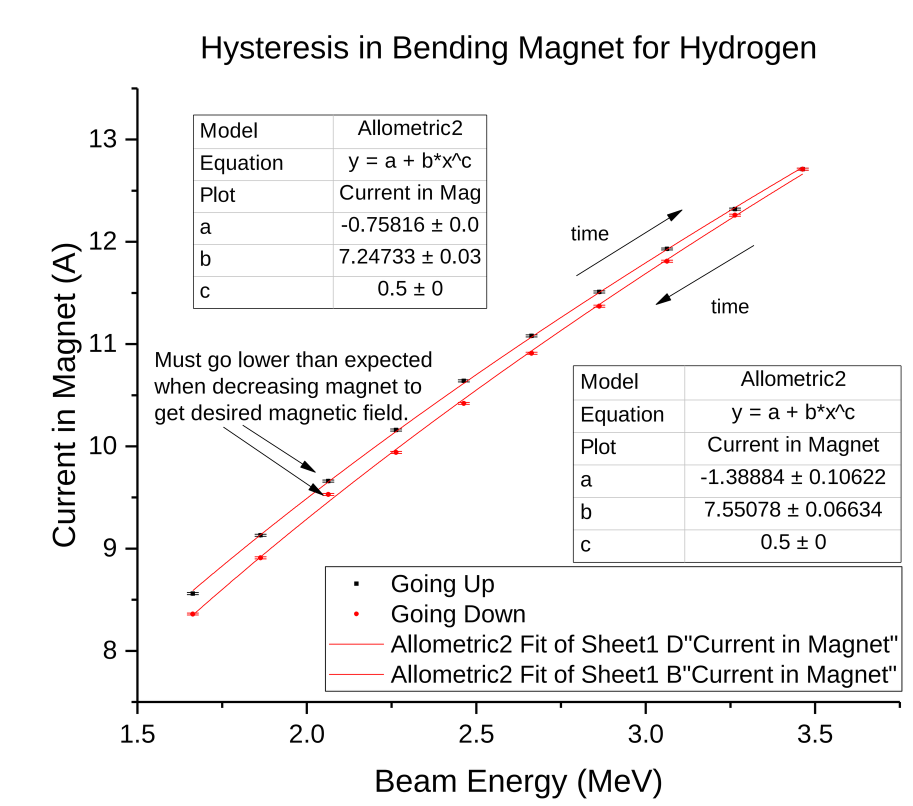

Figure 4: Experimental data for hysteresis in the dipole bending magnet.

Further Work

- Further understanding of the velocity selector.
- Better understanding of beam energies for various terminal voltage settings.
- More accurate and predictable model for hysteresis and saturation in the dipole bending magnet.
- Applications of the beam such as nitrogen implantation.

Acknowledgements

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