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Calibrating the Faraday Cup for Ion Beams Using Rutherford Backscattering Spectroscopy

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Motivation

The high energy ion beams produced by Hope College's particle accelerator are effectively used to generate defects on solid state compounds. Controlling the amount of incident ion beams, we can control the amount of defects created on a sample. In this way, the effect of defects on the properties of novel compounds (i.e., superconductors, topological compounds, and magnetic compounds) can be studied. In order to estimate the amount of defects generated, accurate measurement of the amount of incident particles (current) is necessary. The Aluminum Faraday cup has been used to measure the total current, but its calibration is not reliable. Therefore, we developed a new calibration procedure - calibrating the Faraday cup with Rutherford Backscattering Spectroscopy on pure Copper.

Experimental Setup

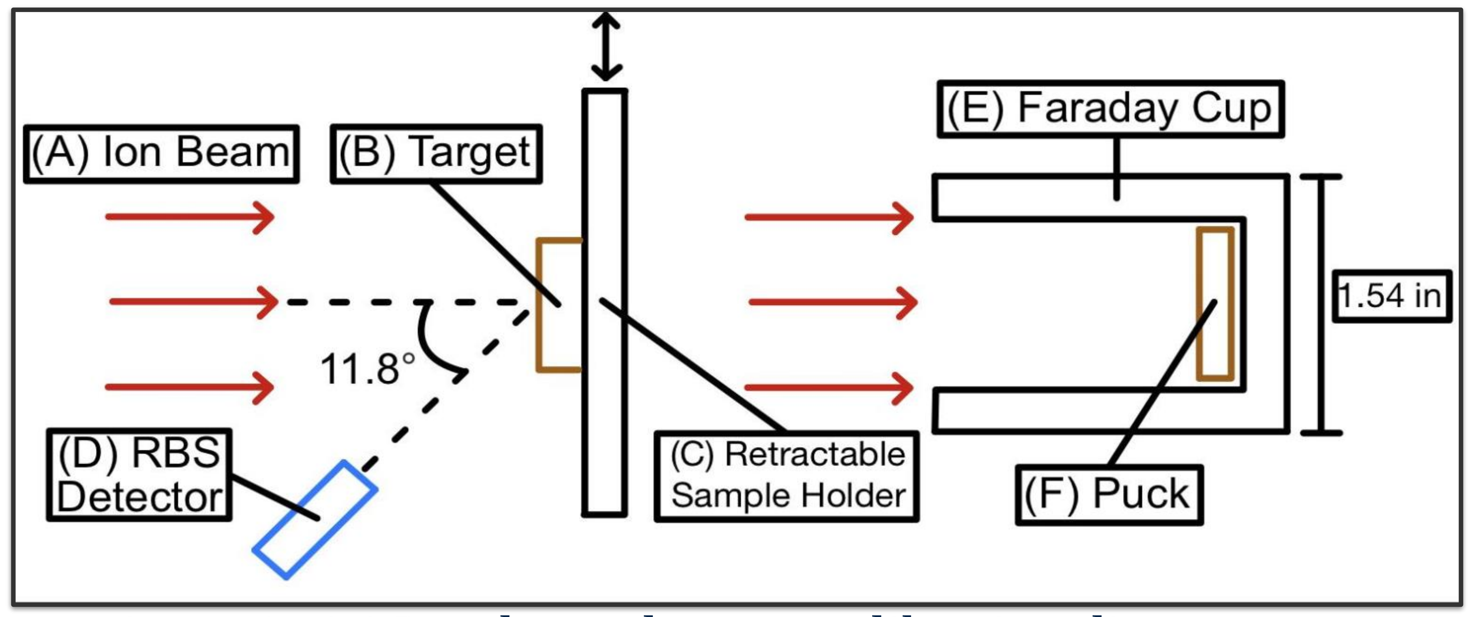


Figure 1. RBS and Faraday cup calibration diagram

(A) Ion Beam: H^+ or He^+
(B) Target: pure Copper (thickness < 5 mm)
(C) Retractable Sample Holder: pure copper is mounted for RBS, it is retracted for Faraday cup measurements
(D) RBS Detector: measures backscattering of the beam and is fixed at an angle of 11.8° from the direction of the beam
(E) Faraday cup: Aluminum cup that measures the current of the ion beam
(F) Puck: Carbon or Tantalum pucks are placed.

Two Methods To Measure Ion Beam Currents

1) Rutherford Backscattering Spectroscopy (RBS): We estimated the current of ion beam by analyzing the RBS data on a pure Copper sample (thickness < 5 mm)
2) Faraday cup measurement: Ion beam current is directly measured using a Faraday cup with/without pucks inside.

Rutherford Backscattering (RBS)

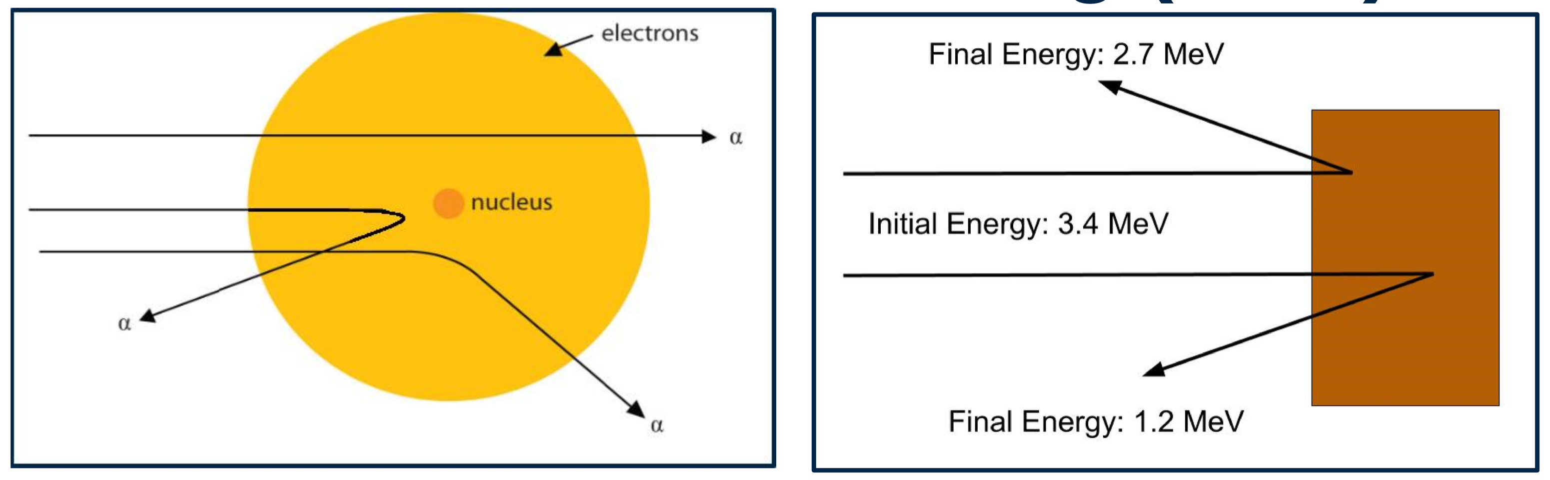


Fig 2. Left panel shows how incident ions interact with atoms, and right panel describes the energy loss of the incident ion depending on depth.

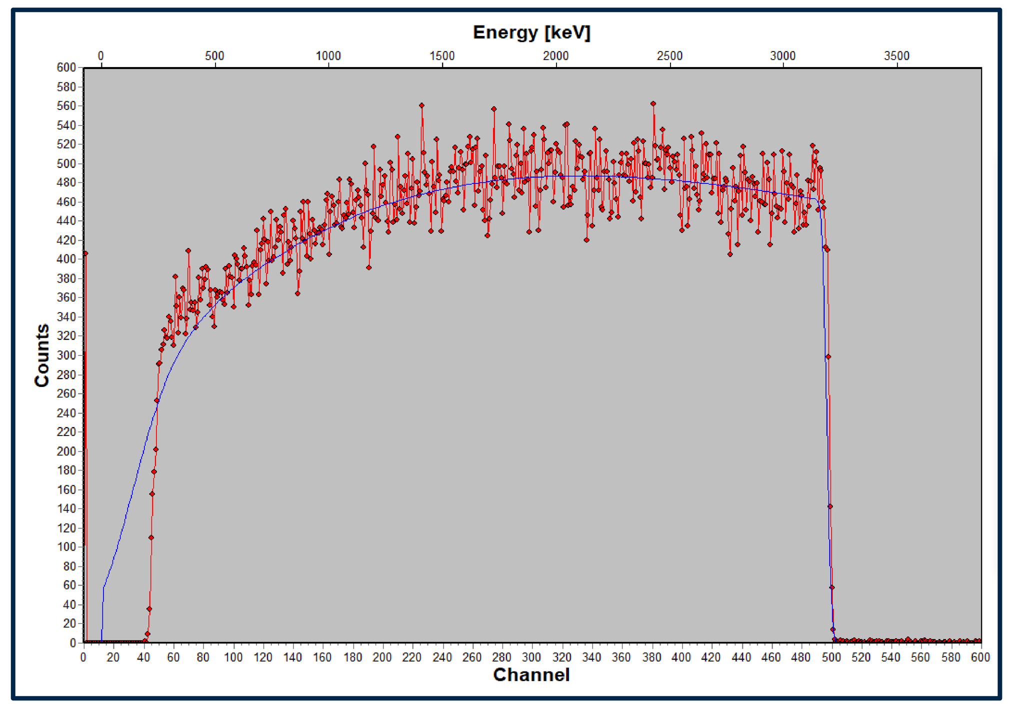
Rutherford Backscattering Spectroscopy powers much of our research. High energy ions moving through a material interact with other atoms in a material. These ions lose more energy as they move deeper in. Thus, by measuring the energy of the ions that "bounce back", we can build spectrums such as the one shown in Figure 3. Spectrums like these can tell us many things about both the ion beam and the impacted material.

Calibration of Current with RBS

$$I = \frac{P * e}{\Omega * t}$$

I = current
P = particles*steradian
Ω = solid angle
e = elementary charge
t = duration of irradiation

This equation shows how to calculate the current of a beam given the particles*steradian. We can find this using SIMNRA, which has us input the parameters of the beam and RBS setup, and then calculates the RBS spectrum for that setup. By varying the particles*steradian, we can find the best parameters that fits RBS data as shown in Figure 3.



Fit Parameters

Incident Ion	H^+
Energy	3.4 MeV
Exit Angle	11.80°
Calibration Offset	-77.0 keV
Energy per Channel	6.58 keV/CH
Particles* Steradian	8.85 x 10^9
Detector Resolution	35.0 keV

Figure 3. Example SIMNRA fit for RBS data (pure Copper)

Results

Cup Puck	Ion Beam	Beam Energy (MeV)	RBS Current (nA)	Faraday Cup Current (nA)	Current Ratio	Uncertainty in Ratio
None	H+	3.40	1.26	1.37	1.08	0.06
None	He+	2.40	1.43	2.89	2.02	0.12
None	H+	3.40	0.49	0.54	1.09	0.06
None	He+	2.85	6.10	12.57	2.06	0.12
None	He+	2.85	14.85	33.58	2.26	0.13
C	H+	3.40	3.63	4.18	1.15	0.07
C	H+	3.40	3.63	4.18	1.15	0.07
C	H+	3.40	5.81	7.13	1.23	0.07
Ta	H+	3.40	2.97	3.22	1.08	0.06
Ta	He+	2.85	9.90	22.51	2.27	0.13
Ta	He+	2.40	0.41	0.91	2.20	0.13

Table 1. Summary on 11 trials. RBS and Faraday cup measurements were conducted varying parameters such as type of ion beam, beam energy, puck insertion and focus of the beam. Results of measured currents are summarized.

$$Current\ ratio = \frac{Current\ (Faraday\ cup)}{Current\ (RBS)}$$

In Table1, the current ratio is calculated with the equation above. The ratio was always greater than 1 for all trials. This was expected due to secondary electron emission. When the ions in the beam come to a sudden halt in the Faraday cup, they are losing a large amount of energy to their environment. Electrons that absorb this energy are often emitted out of the cup, causing increase of current. However, it is still unclear why He^+ beams have such a high current ratio (≈ 2.16) in comparison to H^+ beams (≈ 1.13).

Conclusions

- Faraday cup was successfully calibrated using RBS technique. The calibrated Faraday cup will be used for defect study on novel superconductors.
- It is unclear why He^+ beams have such a high current ratio in comparison to H^+ beams. Further investigation is needed.

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