Effects of Cell Windows on TwinSol Beams

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Abstract. In order to study reactions with unstable nuclei, radioactive-ion beams must be used. One method for producing radioactive beams is the TwinSol experimental setup at the University of Notre Dame. At TwinSol, stable and unstable isotope beams bombard a gas target, where one atmosphere of gas must be confined from the surrounding vacuum. Thin foil windows are used to contain the gas in the cell. In order to optimize the quality of secondary beams from TwinSol, it is necessary to understand and minimize the effects of energy loss and straggling in the windows. This work is the beginning of a process to improve the TwinSol design so that secondary beams produced with heavier ions such as Oxygen, Fluorine, and Neon can be pursued.

1. Introduction

One method to probe nuclear structure is the bombardment of light nuclei with a heavy, radioactive nuclei. However, in the lab, we must replicate the reaction using inverse kinematics because radioactive isotopes cannot be used as a target. In order to isolate the gas target from the vacuum, gas cell windows must be used. This investigation will focus on the effect of the cell windows on TwinSol experiments.

One of the most important properties of gas cell window is that is essentially invisible to the beam. To approach this optimization, a very thin foil may be used. However, as the strength of a foil is proportional to its thickness, very thin foils will not withstand the vacuum. In order to produce a practical amount of reaction products, one atmosphere of gas is typically contained within the cell, and such a pressure gradient leads to stress on the windows. Therefore, a window material has to be relatively strong.

Another key feature of the optimal window material is that it has a low stopping power, \( \frac{dE}{dx} \). Since the stopping power is proportional to \( Z^2 \), a low \( Z \) material will absorb less energy from the beam. Similarly, a low density material will yield lower energy straggling. When the beam passes through the window, it loses energy due to the electric and nuclear forces experienced between the beam and the material. We would like to diminish effects of stopping power and reduce energy straggling in the beam in order to increase the resolution of the beam and thus reduce the error of the calculated cross sections of reactions.

Furthermore, window materials which are thermally conductive will be able to dissipate the heat of the beam, which is focused to a diameter of a few millimeters. Having a low thermal conductivity, however, can be supplemented by having a high melting or degradation temperature. It is also important to note that the initial pressure of the gas cell may greatly increase due to heating of the gas by the beam, yielding greater stress on the window.
Table 1:
Materials used in vacuum and beam experiment.

| Material       | Thickness | Tensile Strength MPa | Density mg/cm³ | Thermal Cond. W/mk | Melting/Degradation Temperature °C |
|---------------|-----------|----------------------|----------------|--------------------|-----------------------------------|
| Titanium      | 5 µm      | 240-370              | 4.90           | 21                 | 1668                              |
| Molybdenum    | 2.5 µm    | 550-650              | 10.8           | 138                | 2623                              |
| Aramid        | 4 and 12 µm | 392-490            | 1.5            | n/a                | 300-350                           |
| Aluminized Mylar | 24 µm  | Aluminum 40-50       | 2.70           | 237                | 660                               |

2. Experimental Design
The gas window used in previous TwinSol experiments were 5 µm Titanium foils. Possible window material alternatives to Titanium are evaluated based on the following properties: tensile strength, malleability, thickness, density, thermal conductivity, melting/degradation temperature, availability, cost. In order to understand durability of materials subject to an ion beam, we used experimental methods as well as theoretical simulations and calculations. Stopping powers of each beam and window material combination were calculated using the SRIM program [1], and these were used to calculate the power and energy implanted in each of the windows. See figure 1. Also, for each material, the maximum current load was calculated using the VTL (Virtual Target Lab) program [2].

The central experiment of this investigation was the vacuum and beam test, which were meant to mimic typical TwinSol conditions. See table 1 for materials tested with the given properties.

In the experiment, a 5+ charge state Carbon beam was accelerated to 42.5 MeV by the FN-tandem accelerator at the University of Notre Dame. 4He gas filled the cells to approximately atmospheric pressure. The pressure inside the gas cells is to be monitored by a digital pressure gauge, and recorded throughout the experiment. The procedure for each test is to begin at a low current of 50 nA for tuning, and then increase the current until the window breaks or significantly leaks.

3. Results
The results of the experiment were very useful in providing the first metrics against which to compare theoretical results. Given the many parameters which must be controlled and the time constraints of the experiment, the materials must be compared with caution.

Table 2:
| Window Material | Integrated Current psA · hr |
|-----------------|-----------------------------|
| 2.5 µm Molybdenum† | 723                         |
| 4 µm Aramid     | 16.7                        |
| 12 µm Aramid    | 273                         |
| 24 µm Mylar no osc. | 16.4                       |
| 24 µm Mylar w osc. | 16.4                       |

Table 2: Titanium window used to align the beam and received the smallest integrated current. The Molybdenum windows received the highest integrated current by a large factor, without failure†. The integrated current of the Aramid and Mylar windows is the total current reached before failure.

3.1. Theoretical Results
Using SRIM stopping power tables, energy loss was calculated for each of the window materials given initial beam conditions. Figure [1] contrasts the fractional energy loss of a range of Carbon beam energies in Titanium and Aramid windows against the thickness of the material.
Figure 1: Calculations using SRIM stopping power tables. Contrast the fraction of beam energy loss in Titanium (a) versus the less dense Aramid (b). Where the gradient is deep red, indicating a fractional loss of 1, all of the beam energy is lost because at low beam energies and high window thicknesses, the beam does not have enough energy to escape the window, so it acts as a beam stop. Even when the thickness of Aramid is double that of Titanium, the energy loss in Aramid is less.

4. Discussion and Future Research
Preliminary results of this investigation indicate that Molybdenum and Aramid may be suitable alternatives to Titanium for TwinSol gas cell windows. If Molybdenum is to be used, a very thin foil, such as the 2.5 $\mu$m, should be used because Molybdenum is a high $Z$ element, compared to Titanium (42 vs. 22). Although this increases its stopping power, Molybdenum has a much higher melting point and thermal conductivity, so it may be advantageous in having a long lifetime of use in experiments. An alternative with opposite characteristics was found to be the Aramid foils. Having a low density of 1.5 g/cm$^3$, this material has a low stopping power, which is optimal for maintaining the resolution of primary and secondary TwinSol beams. However, it may not have a long lifetime of use under high beam currents. Therefore, the specificity of each TwinSol experiment may determine which window material may be ideal.

4.1. Future Work
This investigation was meant to be the beginning of a process to improve the Twinsol design and understand how the gas cell windows affect the primary and secondary beams. From this point, outputs from SRIM and VTL may be used with the accompanying codes for calculations so that more alternatives may be explored. The experimental procedure can be also followed in future tests to compare the material performances. In future experiments of this type, it could be beneficial to implement an infrared heat camera to image the windows and monitor their temperature on line. With this apparatus, theoretical equilibrium pressures from VTL could be compared to experiment.

Although the conditions required for this experiment were considered for TwinSol, understanding the effects of gas cell windows on nuclear beams is not unique to experiments conducted at the University of Notre Dame. For any experiment where a gas target is required, methods for investigating alternative window materials would be beneficial.

References
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