Production and Separation of Radioactive Beams ^{20}Na and ^{20}Mg with MARS

Gopal Subedi, Colby College, Waterville, ME 04901

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Advisor: Dr. Robert E. Tribble

INTRODUCTION

Nuclear physics is vital in understanding the nucleosynthesis and energy production in stars via nuclear reactions. Nuclear astrophysical processes are important in Big Bang, in cataclysmic stellar explosions like supernova, and in stars with very high temperature and densities. Many times we need to study exotic nuclei away from stability and their interactions to understand their importance in astrophysics and cosmology. This is possible by making exotic beams via nuclear reactions in nuclear laboratories on Earth. One such facilities is MARS at Cyclotron Institute, Texas A&M University.

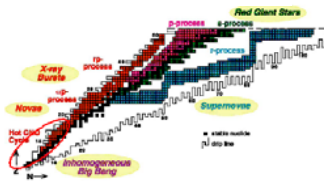


Figure 1: Figure showing the importance of radioactive nuclei in astrophysics. The red and the blue regions represent the unstable nuclei that have been studied. Thousands of radioactive nuclei far from the region of stability are yet to be explored.

WHAT IS MARS AND HOW DOES IT WORK?

Momentum Achromat Recoil Separator

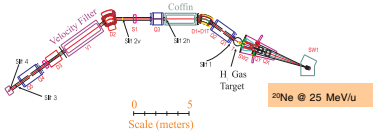


Figure 2: MARS separates reaction products in two ways: magnetic rigidity and velocity selection. Unwanted ions are blocked by closing slits positioned along the beam line.

- Primary beam of ^{20}Ne @ 25 Mev/u from K500 cyclotron.
- Gas cell → 1.5 atm of ^{3}He at 77K.
- Reaction occurs in the gas cell to give the secondary beam (^{20}Mg or ^{20}Na).
- The beam is separated by the magnetic rigidity (p/q = Bρ) using dipole D1and D2.
- The primary beam (^{20}Ne) is stopped with a Faraday cup in the "coffin".
- The slits ("2h") in the coffin define the momentum acceptance of the spectrometer.
- Quadrupole, Q3 and dipole D2 make a momentum achromat to get a parallel beam into the velocity filter.
- Velocity filter and dipole D3 make the final mass selection, q/m in the y-direction.

REU GROUP EXPERIMENT
(^{20}Na Production and its β- decay)

We have used a ^{20}Ne beam @25 MeV/u impinging on a cryogenic gas cell that contained H_2 at p=3.0 atm and T=77 K to produce ^{20}Na, then separate it with MARS, implant it and study its various decays (Fig. 5). There were 3 groups, each with 4 students. Each group performed the experiment independently. The results obtained by three different groups are shown below.

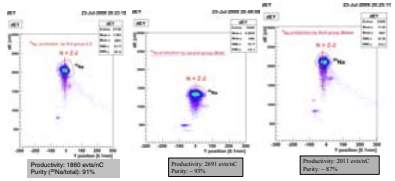


Figure 3. Production of ^{20}Na as obtained by three different groups. The overall productivity rate was best obtained by the second group using a 5 mil Al degrader. The figures simply show the center ion of interest (^{20}Na) in "y" by matching Bρ of D3 to velocity v selected by the velocity filter.

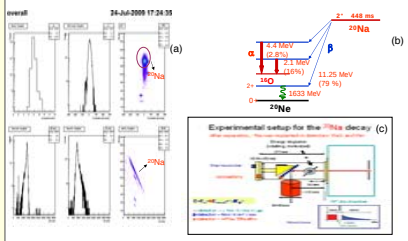


Figure 4: Fig (a) shows the final ^{20}Na production spectra showing the position of the beam in the focal plane. Fig (b) represents the ^{20}Na decay scheme with branching ratios. Fig (c) shows the experimental setup for the ^{20}Na decay studies.

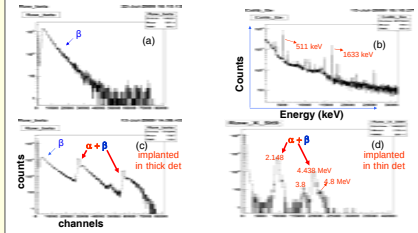


Figure 5: Results showing the decay of ^{20}Na. Fig (a) shows the β- decay spectrum. Figure (b) shows the γ- ray spectrum in the gamma single mode run. Figure (c) shows both the α + β decay when ^{20}Na was implanted in the thick detector. A better resolution is seen in fig (d) since there is less background (less β energy loss).

^{20}Mg PRODUCTION AND SEPARATION

Two different reactions were employed to obtain the best production of ^{20}Mg isotope. Projectile fragmentation of ^{24}Mg @48 MeV/u on ^{9}Be done in Feb, 2009 and fusion-evaporation of ^{3}He(^{20}Ne,^{20}Mg)3n @25 MeV/u done in June. The code LISE was used to obtain the predictions before conducting the actual experiment. The results are shown below.

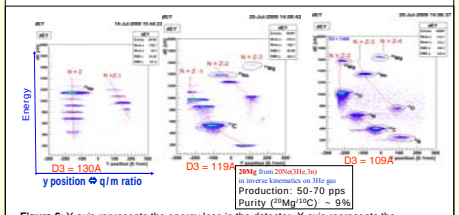


Figure 6: Y-axis represents the energy loss in the detector. X-axis represents the position of the beam as it hits the end of the spectrometer.

For different charge to mass ratio (q/m), particles are in different hyperbolas. Particles with same q/m have same position in y after the velocity filter. However, the energy loss is different for each particle as they carry different charges. The figures from left to right in figure 6 represent the results obtained for different D3 magnetic field settings.

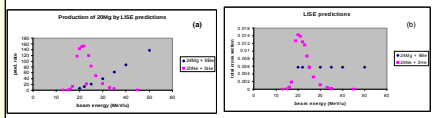
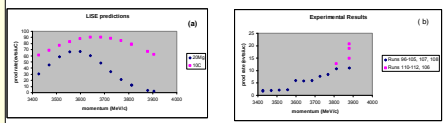


Figure 7: Plots showing the LISE predictions for ^{20}Mg production for both projectile fragmentation and fusion evaporation reaction.

In figure (7a), LISE predicted that we could observe about the same production rate for ^{20}Ne + ^{3}He @ 22 MeV/u and ^{24}Mg + ^{9}Be @ 48 MeV/u. In (b), the maximum cross section occurs at about 20 MeV/u for fusion-evaporation while it remains flat for fragmentation (LISE does not predict variation of cross section in projectile fragmentation with beam energy). When the cross section starts decreasing for fusion evaporation, the production rate also declines. Production rate depends on cross section and the transport efficiency through the spectrometer. In (b), although ^{20}Ne + ^{3}He at 20 MeV/u has higher cross section, the efficiency of transport is low with less forward focused products. Thus, to get the same production rate for ^{20}Ne + ^{3}He at 22 MeV/u, we use more intense beam (~10 – 100 X).



(c)

Figure 8: Figure (a) shows the LISE predictions for production rate as a function of momentum. Figure (b) shows the experimental results.

LISE predicted that the production rate for ^{20}Mg is maximized at around 3580 MeV/c. However, the highest rate observed in the experiment was at about 3900 MeV/c. The reason for this difference lies in our assumption that the reaction mechanism would be fusion- evaporation in our LISE calculations. However, the experimental results indicate that the reaction could be some combination between fusion and transfer. In (8b), multiple data points at the same momentum show results for different runs where we tried to optimize the beam optics.

CONCLUSIONS AND FUTURE PERSPECTIVES

The production and separation of ^{20}Mg was carried out using two different reaction mechanisms so as to ascertain the best method of producing ^{20}Mg. The overall production of ^{20}Mg was better with fusion-evaporation reaction ^{20}Ne + ^{3}He because higher beam currents were available for ^{20}Ne. This established, the next step will be to study the β-delayed proton decay of ^{20}Mg. The decay measurement is planned for study by the MARS group at Cyclotron Institute, TAMU in collaboration with a group from the Univ of Edinburgh, UK. The study of the states populated in the decay would help to better understand the resonances in the ^{19}Ne (p,γ) ^{20}Na reaction. It will reduce the uncertainty in the predicted rate of a reaction which is considered to be the main breakout from the CNO cycles into the rp-process in astrophysical phenomena such as X-ray bursts.

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