Research in Experimental Nuclear Astrophysics

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Topics

- Master's Work at CSM
- PhD Work at TAMU
- Post Doc in Collaboration with LLNL
Masters Work
Beam Stripping in the Driver Accelerator at the Rare Isotope Accelerator

• **Summary of Project:**
  - Investigated the thermodynamics of stripper foils placed in beam

  - Foil Materials
    - C, Be, Al, Ti, V, Cu, Ag and Au

  - Simple Calculations done with *Mathematica*

  - More complex heat flow simulations done with *SOLIDWOKS + COSMOSWORKS*
• **In Conclusion:**

  - **CAD Programs:**
    - AutoCAD
    - SOLIDWORKS

  - **Calculation Tools:**
    - Mathematica
    - MATLAB

  - **Data Analysis Tools:**
    - ROOT
PhD Work
Astrophysical Observation

- First & most well observed gamma ray line from $^{26}\text{Al}$
  - First observed in 1982 by the HEAO-C Satellite

- Ongoing nucleosynthesis
  - Dynamic Universe!

- Excess of $^{26}\text{Mg}$ in carbonaceous chondrites
  - Implications on the age of the solar system
Astrophysical Interest

- Creation site of $^{26}\text{Al}$ is still under debate
  - WR & AGB Stars
  - Classical Novae
  - Core Collapse Supernova

- For $^{26}\text{Al}^g$ & $^{26}\text{Al}^m$:
  - Below temps of $\sim$1 GK
    - Separate Species
  - Above these temps
    - Correlated

The study of reactions for production and destruction of ALL $^{26}\text{Al}$ are of high interest. I will focus on $^{26m}\text{Al}(p,\gamma)^{27}\text{Si}^*$; dominated by resonant capture process.
Top of the Barrier

\[ \omega \gamma = \frac{2J + 1}{(j_p + 1)(j_t + 1)} \frac{\Gamma_{\text{proton}} \Gamma_\gamma}{\Gamma_{\text{proton}} + \Gamma_\gamma} \]

At the top of the barrier: \( \Gamma_{\text{proton}} \gg \Gamma_\gamma \)

\[ \omega \gamma \approx \omega \Gamma_\gamma \]

Mostly Protons!
Bottom of the Barrier

\[ \omega \gamma = \frac{2J + 1}{(j_p + 1)(j_t + 1)} \frac{\Gamma_{\text{proton}}}{\Gamma_{\text{proton}}} \frac{\Gamma_\gamma}{\Gamma_\gamma + \Gamma_\gamma} \]

At the bottom of the barrier: \( \Gamma_{\text{proton}} \ll \Gamma_\gamma \)

\[ \omega \gamma \approx \omega \Gamma_{\text{proton}} \]

Mostly Gammas!
Slightly Above the Proton Threshold

\[ \omega \gamma = \frac{2J + 1}{(j_p + 1)(j_t + 1)} \frac{\Gamma_{\text{proton}} \Gamma_{\gamma}}{\Gamma_{\text{proton}} + \Gamma_{\gamma}} \]

Slightly Above the Proton Threshold: \( \Gamma_{\gamma} \gg \Gamma_{\text{proton}} \)

\[ \omega \gamma \approx \omega \frac{\Gamma_{\text{proton}}}{\Gamma_{\gamma}} \Gamma_{\gamma} \approx \omega \frac{b_{\text{proton}}}{b_{\gamma}} \left( \frac{\hbar}{\tau} \right) \]
The **Beta-Delayed** Proton Decay Study of $^{27}$P

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No experiment has been able to produce clean and abundant $^{27}\text{P}$ to study in detail its $\beta p$ and $\beta \gamma$ decays.
Previous Experiments at TAMU

**26 Al Destruction Rate in Novae**

\[ ^{27}\text{P} \rightarrow ^{27}\text{Si}^* \Rightarrow ^{26}\text{Al}(p,\gamma)^{27}\text{Si}^* \]

**22 Na Depletion in Novae**

\[ ^{23}\text{Al} \rightarrow ^{23}\text{Mg}^* \Rightarrow ^{22}\text{Na}(p,\gamma)^{23}\text{Mg}^* \]

**Bottleneck r. in Novae**

\[ ^{31}\text{Cl} \rightarrow ^{31}\text{S}^* \Rightarrow ^{30}\text{P}(p,\gamma)^{31}\text{S}^* \]

**Breakout of HCNO to rp-Process**

\[ ^{20}\text{Mg} \rightarrow ^{20}\text{Na}^* \Rightarrow ^{19}\text{Ne}(p,\gamma)^{20}\text{Na}^* \]
Separate the Desired Fragment \((^{27}\text{P})\)

**Momentum Achromat Recoil Separator**

- **Gas Cell Target** produces nuclei (in-flight & in inverse kinematics)
- **Primary Beam**: \(^{28}\text{Si}\) @ 40 MeV/u from K500
- **The Implantation-Decay Station**

\(^{27}\text{P} @ \sim 35\text{ MeV/u}\)

Scale (meters)
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Total Impurities ~11%

For: $^{27}\text{P}$: $\to 2.9$ evts/nC
Basic Experimental Procedure

\[ \Delta p/p = \pm 0.25\% \]

Pulsed Beam

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Electronics!
Implantation

Location of true implantation

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Gamma Analysis

Peak ID in $^{27}$Si Spectrum
Future Outlook
The AstroBox Prototype

*Designed and built in collaboration with CEA Saclay (Dr. E Pollacco) and CERN*
• **Goals for New Detector:**
  – Less sensitive to β-particles
  – Good Resolution  
    • 10-20 keV (FWHM) at 200 keV
  – Uniform Efficiencies  
    • About 10-20%

• **Less Sensitive to Betas:**
  – Active gas volume  
    • Very little energy loss for the betas

• **Good Resolution & Efficiency:**
  • Solved by the use of a new detector design  
    • MICROMEGAS (MICRO-MEsh-GAseous Structure)
**Two Main Regions:**
- The *Conversion Gap*
- The *Amplification Gap*

**Applying Voltages:**
- A very high E-Field in the amplification region
- A low E-Field in the drift region
- Ratio between the two gaps can be large
  - Required for an optimal functioning of the device
Gas Bottle

Regulator

Pressure Regulator

V1

AstroBox Chamber

250 torr

Deg Chamber

MARS Chamber

V2

Valve

Flow Meter (Optional)

Flow Meter

Rough Pump

Valve on Pump

Cu Tubing

3/8” OD

1/4” OD

V3

800 torr

V4

P10 or P05

Gas Flow System

800 torr

V5

Dry N₂

~8.5 L/hr

Flow Valve

P10 or P05

800 torr

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Back End of MARS

Al Degrader

Gas Flow System

Output Signals and Pre-Amplifier Units

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Implantation Method

MICROMEGA
Implantation Method

MICROMEGA
Proton Response
First Test Run (P10)

Clean Spec Down To ~100 keV
Stats after only 3.5 hrs

Resolution ~ 13% for 267 keV
Proton Response
Second Test Run - P10 vs P05

Resolution ~ 13.55% for 267 keV

Resolution ~ 10.5% for 267 keV

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Heavy Ion Response

Resolution ~ 5% for $^{23}$Al

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  - IRFU, CEA Saclay
  - *Institut fuer Kernphysik der Universitaet zu Koeln
**In Conclusion:**

- **CAD Programs:**
  - AutoCAD
  - SOLIDWORKS

- **Data Analysis Tools:**
  - ROOT
  - C++
  - Simulations
    - Lise++/SRIM
    - Geant4

- **Lab Skills:**
  - Detectors
  - Electronics
  - Experimental Procedures
Post Doc Work/Plans
Ion Interactions Line (STARLiTeR)  
(Silicon Telescope Array for Reaction Studies)

- **Large Collaboration:**
  - Multiple National Labs and Universities Collaboration
    - Mainly from LLNL
    - People from several countries
  - Originally Set Up at Berkeley
    First In place here in 2012

- **Experiments:**
  - Tagged Transfer Reaction Study
  - Surrogate Technique to Obtain Cross Sections
    - “Populating the same compound nucleus using a longer-lived target”
    - For Neutron Capture, Neutron Induced Fission and (n,2n) cross sections
  - Currently up to 6 Ge Clover Detectors
    - Upgrade for more coming soon
  - Up to 4 Si Detectors
    - 2 upstream and 2 down stream of a target placed on a rotating wheel
Solid Target

Silicon Detectors

Clover Germanium Detectors

Beam
Desired Reaction

\[ \text{n} \rightarrow \begin{array}{c} 237 \text{U} \\ (6.75 \text{ days}) \end{array} \rightleftharpoons \begin{array}{c} 238 \text{U}^* \end{array} \]

Surrogate Reaction

\[ \alpha \rightarrow \begin{array}{c} 238 \text{U} \\ (4.47 \times 10^9 \text{ years}) \end{array} \rightleftharpoons \begin{array}{c} 238 \text{U}^* \end{array} \]
Collaborators
(undergraduate students, graduate students, post-docs)


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