Is it Possible to Study $^{44}\text{Ti}(\alpha,p)^{47}\text{V}$ Reaction with Radioactive Target?

Tariq Al-Abdullah$^{(1,2)}$, D. Bemmerer$^{(2)}$, K. Schmidt$^{(2)}$, D. Schumann$^{(3)}$, R. Dressler$^{(3)}$, M. Ayranov$^{(3)}$

$^1$Hashemite University, Zarqa-Jordan,
$^2$HZDR, Dresden-Germany,
$^3$PSI, Villigen-Switzerland

PSI 31.08.2011, Villigen/Switzerland
Main Points

- The Importance of $^{44}\text{Ti}$ in Supernovae.
- The Reaction Rate for $^{44}\text{Ti}(\alpha,p)^{47}\text{V}$ at Astrophysical Energies.
- Problems with Radioactive $^{44}\text{Ti}$ Target.
- The Safety Concerns of the Experiment.
- Suggestions and Future Plans.
The importance of $^{44}$Ti in supernovae.

- $^{44}$Ti, $t_{1/2}=58.9 \pm 0.3$ yr\(^{(1)}\).
- Its $^{44}$Ti → $^{44}$Sc, 78.4 & 67.9 keV.
- $^{44}$Sc → $^{44}$Ca, $\gamma$-lines at 1157 keV.
- 1.157 MeV has been observed from Cassiopeia A by X-rays & $\gamma$-rays telescopes [CGRO, RXTE, INTEGRAL] \(^{(2)}\).
- The ejected $^{44}$Ti is estimated: $1.6^{+0.6}_{-0.3} \times 10^{-4} M_\odot$ \(^{(3)}\).
- At $T_g=4.3$, its abundance grows after $\alpha$-rich freezeout.
- The yield is sensitive to: $^{40}$Ca($\alpha,\gamma$)$^{44}$Ti, $^{44}$Ti($\alpha,p$)$^{47}$V, $^{44}$Ti($\alpha,\gamma$)$^{48}$Cr, $^{45}$V($p,\gamma$)$^{46}$Cr.
- L.-S. The\(^{(4)}\): $^{44}$Ti($\alpha,p$)$^{47}$V is the most important reaction.

---

\(^{(1)}\) I. Ahmad et al, PRC 74, 065803 (2006).
\(^{(4)}\) L.-S. The et al., Astropjys. J. 504, 500 (1998)
The reaction rate for $^{44}\text{Ti}(\alpha,p)^{47}\text{V}$ at astrophysical energies.

- This reaction is measured in inverse kinematics by:
  - Energy range: $5.7 \text{ MeV} \leq E_{c.m.} \leq 9 \text{ MeV}$, using a beam of $^{44}\text{Ti}$

- The estimated reaction rate is a factor of $2$ greater than the theoretical calculations, with uncertainty of $37\%$. 
The reaction rate for $^{44}\text{Ti}(\alpha,\text{p})^{47}\text{V}$ at astrophysical energies.

- Old Gamow peak: An overlap between MB-distribution and Coulomb barrier penetration [Rauscher et al, PRC 81, 045807 (2010)].

- Not good if $\alpha$-width is changing rapidly with the Coulomb barrier.

- The true Gamow Window

$$ N_A(\tilde{\sigma}_j^{\mu}, \nu) = \frac{3.732 \times 10^{10}}{\hat{A}^{1/2} T_9^{3/2}} \int_0^\infty \tilde{\sigma}_j^{\mu} E_j^{\nu} \exp\left(-11.605 E_j^{\nu}/T_9\right) dE_j^{\nu}, \quad (4) $$

- The reaction rate is re-evaluated R. D. Hofmann; [Astronphys. J. 715, 1383 (2010)].

- The most relevant temp. range is $1 \leq T_9 \leq 5$.

- Cross sections at lower energies dominate both the rates and uncertainties.

- Larger uncertainty in the rate ($\pm 3$) $\Rightarrow$ large uncertainty in $^{44}\text{Ti}$ synthesis
The planned radioactive $^{44}$Ti target.

- A 10-50 MBq radioactive target will be prepared in PSI, [D. Schumann, ERAWAST-PSI].

- For 10 MBq, $D=20$ mm, $T_{1/2}=58.9$ yr, using

$$N = \frac{A}{L}, \quad L = \frac{\ln 2}{T_{1/2}}$$

- $\rightarrow N=2.68 \times 10^{16}; \; ^{44}$Ti

- The thickness of the ($^{44}$TiO$_2$) target is almost 45 nm, or 11 $\mu$g/cm$^2$.

- 0.2 $\mu$m-Gold will coat the radioactive area.

- Stainless steel support: 0.5 mm thick, 27 mm in diameter.

- High purity target is required, no impurities from $^{46-50}$Ti isotopes.
Possible Experimental Setup

- ION-Beam Center at HZDR.
- Q-Value = -- 0.41 MeV.
- $\alpha$-beam at 4-7 MeV, Angle = 55°. Current = 1 $\mu$A for 1-2 weeks.
- 25 $\mu$m Al-foil is used to stop $\alpha$-particles before the detector.
- 100-300 $\mu$m PIPS [Partially Implanted Passivated Silicon].
Can $^{44}$Ti($\alpha$,p)$^{47}$V be performed?

- Starting with simple setup [500 $\mu$m-Ortec Si-detector with AmCmPu source].

- For $^{241}$Am main peak, $E = 5486 \pm 21$ keV.
Can $^{44}\text{Ti}(\alpha,p)^{47}\text{V}$ be performed?

- AmCuPu-source and $^{44}\text{Ti}$ (83 kBq) are both observed by the 500 µm Si-detector.
- A strong increase in the background continuum; 1 % to 94 % counting rate.
- Continuum ends point is at almost 1.7 MeV.
- IS IT GOOD?
Can $^{44}\text{Ti}(\alpha,p)^{47}\text{V}$ be performed?

- Detecting the protons after the reaction.
- Using Lise & Trim codes.
- Starting at $E_\alpha = 4 \text{ MeV} \rightarrow \text{Gold} \rightarrow E_\alpha = 3.82 \pm 0.04 \text{ MeV}$
- $E_p = 2.8 \text{ MeV} \rightarrow \text{Au} & \text{Al} \rightarrow E_p = 2.12 \pm 0.08 \text{ MeV}$.

Similarly for $E_\alpha = 6 \text{ MeV},$
- $E_p = 4.49 \text{ MeV} \rightarrow \text{Au} & \text{Al} \rightarrow E_p = 4.03 \pm 0.08 \text{ MeV}$.

- Protons peaks do not overlap with the continuum.
- PIPS detectors can be used.
- The height of the peaks is in random units.
Problems with radioactive $^{44}$Ti target.

- Using the 83-kBq $^{44}$Ti source.
- The relation between the activity and the distance for the continuum background is:

$$A = 11473 \times \frac{1}{r^2} + 247 \ [c/s].$$

- The estimated continuum background for 10MBq-target is:

<table>
<thead>
<tr>
<th>Dist. [cm]</th>
<th>Rate [c/s]</th>
<th>10 MBq [c/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>706</td>
<td>5.5E+4</td>
</tr>
<tr>
<td>10</td>
<td>362</td>
<td>1.4E+4</td>
</tr>
</tbody>
</table>

![Graph showing the relation between $1/r^2$ and Rate]
Problems with radioactive $^{44}$Ti target.

- Several runs with Am and $^{44}$Ti sources are collected at the same geometry.
- Estimating the proton peaks in 300 $\mu$m Si-detector. $E_\alpha = 4, 4.5, 5, 6, 7$ MeV.
- The background from the cosmic rays hide peaks for $E_\alpha \leq 4.5$ MeV.
The Feasibility of the $^{44}\text{Ti}(\alpha, p)^{47}\text{V}$

- Adopting Rauscher calculations, PRC 81, 045807 (2010).
- Gamow Windows are re-calculated for $T_g = 2, 3, 5$.
- Talys code is used. [A. J. Koning, AIP 769, 1154 (2005)]
- Three new points are very probable to measure. Two more are question marks.
Can $^{44}_{\alpha}\text{Ti}(\alpha,p)^{47}_{\text{V}}$ be performed?

- Estimating the yield at 5 & 10 cm between the target and the detector:
- Efficiency: 5 cm $\rightarrow$ 9.6E-3, 10 cm $\rightarrow$ 2.4E-3.
- The reaction is feasible for $E_{lab} \geq 4$ MeV.

<table>
<thead>
<tr>
<th>$E_{lab}$ [MeV]</th>
<th>$\sigma$ [mb]</th>
<th>Dist. 5-cm [Count/hr]</th>
<th>Dist. 10-cm [Count/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>8.96E-4</td>
<td>1.6</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>1.11E-2</td>
<td>20.3</td>
<td>5.8</td>
</tr>
<tr>
<td>5</td>
<td>4.59E-1</td>
<td>84.1</td>
<td>21.0</td>
</tr>
<tr>
<td>6</td>
<td>6.26E+0</td>
<td>1.15E+4</td>
<td>2.87E+3</td>
</tr>
<tr>
<td>7</td>
<td>3.79E+1</td>
<td>7.27E+4</td>
<td>1.82E+4</td>
</tr>
</tbody>
</table>
The Safety Concerns of the Experiment.

- The sputtering of the radioactive atoms from the target.

- Several calculations are made using TRIDYN_FZD code*. [Dr. M. Posselt, HZDR] [W. Möller & W. Eckstein, NIM B 2, 814 (1984)].

- Parameters: Fluence = $10^{19}$ atoms/cm$^2$ [1 µA-10 days], NH = $10^8$ [quality], $E_{\alpha} = 6.0$ MeV @ 55°, TiO$_2$ [450 °A], Layers [ Au varying, Cr = 50 °A]

<table>
<thead>
<tr>
<th>Au-Thick</th>
<th>20</th>
<th>50</th>
<th>200</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>-105.7</td>
<td>-91.2</td>
<td>-69.6</td>
<td>-58.7</td>
<td>-55.8</td>
<td>-38.8</td>
</tr>
<tr>
<td>Ti</td>
<td>24359</td>
<td>17058</td>
<td>7284</td>
<td>920</td>
<td>34</td>
<td>9</td>
</tr>
<tr>
<td>O</td>
<td>219922</td>
<td>216518</td>
<td>79827</td>
<td>8160</td>
<td>271</td>
<td>16</td>
</tr>
<tr>
<td>Cr</td>
<td>84656</td>
<td>83628</td>
<td>33066</td>
<td>5106</td>
<td>389</td>
<td>196</td>
</tr>
<tr>
<td>Au</td>
<td>34417</td>
<td>84578</td>
<td>241035</td>
<td>320695</td>
<td>337291</td>
<td>334982</td>
</tr>
<tr>
<td>Total</td>
<td>435354</td>
<td>401782</td>
<td>361212</td>
<td>334881</td>
<td>337985</td>
<td>335248</td>
</tr>
</tbody>
</table>
The Safety Concerns of the Experiment.

- For our case: when the thickness of the Gold is 0.2 µm.
- The depth profiles of the components for $10^{19}$ ions/cm$^2$ fluence shows a strong mixing between the atoms at all depths.
- Decreasing the fluence will rapidly decrease the sputtered $^{44}\text{Ti}$ atoms.

In worst case, Au-20 °A thick FL = $10^{19}$/cm$^2$, the sputtered $^{44}\text{Ti}$ is 25 k $\Rightarrow$ 10 µBq.
The Safety Concerns of the Experiment.

Estimating the amount of the absorbed dose [Sv/h].

For 10 MBq $^{44}$Ti/$^{44}$Sc source

Dose rate at 1 m distance from the source

$$4 \ \frac{\mu Sv}{h} \iff 8 \ \frac{mSv}{yr}$$

Controlled Area

In case of swallowing the source

10 MBq $^{44}$Ti/$^{44}$Sc source

$\rightarrow$ 66 mSv $\iff$ total dose

$\rightarrow$ If it is not digested, the hazard is small.
Suggestions and Future Plans.

- Measuring the sputtering yield experimentally with an inert target.
- An inert target is prepared and available, [D. Schumann, PSI].
- The target has the same properties as the radioactive one.
- Sputtered atoms will be collected on a catcher, $^{12}\text{C}$, 0.5-1 µm.
- A Secondary Ion Mass Spectroscopy (SIMS) technique.

→ Analyze the composition of the target surface and the catcher.
Suggestions and Future Plans.

• The continuum background from the cosmic rays can be reduced with using a telescope-detection system.

• Two particle detectors PIPS; $\Delta E$ (25 $\mu$m) & E (300 $\mu$m).

• More PIPS detectors inside the chamber at different reaction angles will be good.

• Monte-Carlo simulation; GEANT 4.

• Calculate the efficiency of the detectors.

• Estimate the height of the peaks.

• Reduce the background.
Legitimacy!

- The experiment can not be performed until:
  
  - Getting the 10-50 MBq $^{44}$Ti-target.
  
  - $\sim$MBq is high $\Rightarrow$ several permissions and paper works.
  
  - Quite a few tools need to be available.
  
  - More than a few test runs must be made.
Summary & Conclusion

- The $^{44}\text{Ti}(\alpha,p)^{47}\text{V}$ reaction is possible with:

$$ + = \frac{44}{\text{Ti}}(\alpha,p)^{47}\text{V}$$

- Look for promising results that are better than those from radioactive beam facilities.
Thank you