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Study of the ^{44}Ti(α, p)^{47}V reaction rate using high-precision ^{50}Cr(p, t)^{48}Cr measurements

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Abstract. The abundance and distribution of ^{44}Ti tells us about the nature of the core-collapse supernovae explosions. There is a need to understand the nuclear reaction network creating and destroying ^{44}Ti in order to use it as a probe for the explosive mechanism. The ^{44}Ti(α, p)^{47}V reaction is a very important reaction and it controls the destruction of ^{44}Ti. Difficulties with direct measurements have led to an attempt to study this reaction indirectly. Here, the first step of the indirect study which is the identification of levels of the compound nucleus ^{48}Cr is presented. A 100-MeV proton beam was incident on a ^{50}Cr target. States in ^{48}Cr were populated in the ^{50}Cr(p, t)^{48}Cr reaction. The tritons were momentum-analysed in the K600 Q2D magnetic spectrometer at iThemba LABS.

1. Astrophysical motivation

Core-collapse supernovae (CCSNe) play an important role in galactic chemical evolution, ejecting newly synthesised material into the interstellar medium. Some of the ejected material consists of radioactive nuclei. The decay chains of these nuclei provide a window into understanding the mechanism through which CCSNe take place. One of the most powerful observation targets is

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^{44}Ti which decays into ^{44}Ca via ^{44}Sc, a decay chain containing a number of easily identifiable γ-ray transitions which may be observed by space-based γ-ray telescopes [1]. Since ^{44}Ti can only be produced in α-rich freezeout, it provides a diagnostic measure of the behaviour of supernovae. The amount of ^{44}Ti produced is sensitive to the density, temperature and electron fraction of the deepest layer ejected. However, the amount of ^{44}Ti is also dependent on a number of important nuclear reactions [2-4], among which is ^{44}Ti$(\alpha, p)^{47}$V.

The cross section of the ^{44}Ti$(\alpha, p)^{47}$V reaction depends on the properties of the compound nucleus, ^{48}Cr, mediating the reaction. Since there is not much information on states in ^{48}Cr, statistical models [5] have been used to try to extrapolate the ^{44}Ti$(\alpha, p)^{47}$V cross section from the available data [6,7] into the astrophysical region of interest (E_{cm} = 2.1 - 6.1 MeV). Without experimental data to constrain the cross sections, statistical models vary up to a factor 100 for the ^{44}Ti$(\alpha, p)^{47}$V reaction [8].

In order to resolve the remaining uncertainties in the ^{44}Ti$(\alpha, p)^{47}$V reaction, due to the lack of experimental data on resonance level contributions and cross sections in the region of interest, we report an experimental study of the ^{50}Cr$(p, t)^{48}$Cr reaction using the K600 magnetic spectrometer at iThemba LABS [9]. This reaction is dominated by neutron pair transfer from the even-even $J^{\pi} = 0^{+}$ ground state of ^{50}Cr, favouring natural parity states. In the past, the (p, t) reaction has been used to study natural parity resonances in ^{26}Si [10] and ^{22}Mg [11]. The natural parity states in ^{48}Cr could act as resonances for the ^{44}Ti$(\alpha, p)^{47}$V reaction. Data were collected in coincidence with the Coincidence Array for K600 Experiments (CAKE) [12] and the data reduction is now in progress.

2. Experimental setup

A 100-MeV proton beam was extracted from the Separated-Sector Cyclotron at iThemba LABS. The beam was transmitted down a dispersion-matched beamline to the target position of the K600. The target consisted of enriched 0.75 mg/cm^2 ^{50}Cr evaporated onto a 0.4 mg/cm^2 carbon foil. The beam and reaction products passed into the K600, which was placed with the aperture at 0 degrees. The unreacted proton beam was stopped on a Faraday cup placed within the first dipole of the K600. The other reaction products were momentum-analysed in the K600 and were incident upon a detector system placed at the focal plane. This detector system included two drift chambers providing horizontal and vertical position information, allowing the trajectory of the reaction products at the focal plane to be reconstructed, and a plastic scintillator which provided an experimental trigger, a timing signal and a residual energy measurement. Tritons were identified by considering the time-of-flight through the K600 and the residual energy loss. Kinematic aberrations in the focal-plane spectra were corrected offline based on the focal-plane scattering angle to optimise the resolution.

3. Data analysis and results

The focal plane was calibrated in rigidity using the ^{24}Mg$(p, t)^{22}$Mg reaction. Using the calibration parameters extracted with ^{22}Mg excitation energies combined with kinematic calculations, the excitation energy of states in ^{48}Cr populated in the ^{50}Cr$(p, t)^{48}$Cr reaction was reconstructed (see Figure 1). The experimental energy resolution was found to be around 80 keV (FWHM) on average. The background from ^{12}C$(p, t)^{10}$C and ^{16}O$(p, t)^{14}$O reactions was characterised using data taken with $^{\mathrm{nat}}$C and Mylar targets and the contaminant states are labelled in Figure 1. There could also be peaks resulting from ^{13}C and ^{18}O contaminants since carbon and oxygen are present with natural abundances in the chromium target. These contaminants can be identified with the background runs.

Fifty-nine (59) excited states were observed in ^{48}Cr. Forty-nine (49) of these are observed for the first time in this work. Existing ^{50}Cr$(p, t)^{48}$Cr data were available only up to 7 MeV [13], which is below the α-particle threshold (7698(7) keV) in the ^{44}Ti$(\alpha, p)^{47}$V reaction. The

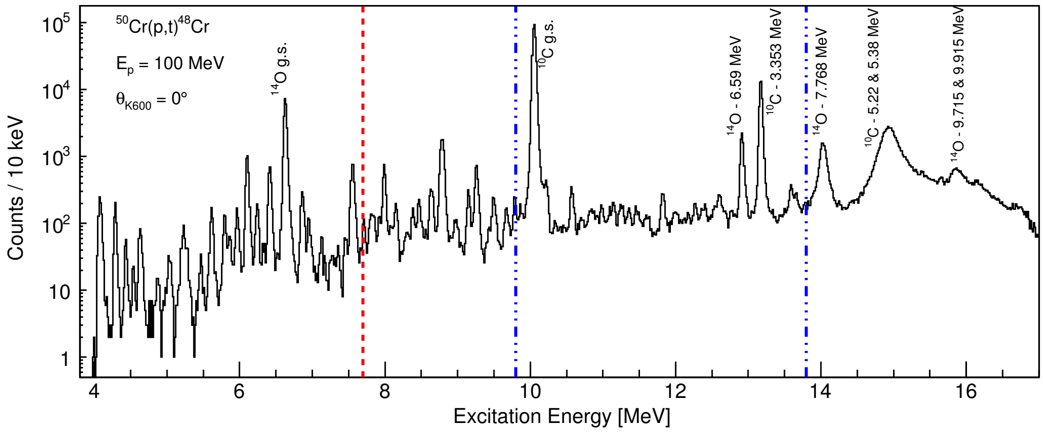

Figure 1. The ^{50}Cr$(p,t)^{48}$Cr excitation-energy spectrum. The red dashed line marks the α threshold (7698(7) keV). The blue double-dotted dashed lines defines the region of astrophysical interest ($E_{\mathrm{x}} \approx$ 9.8 - 13.8 MeV).

most important feature in the ^{48}Cr spectrum in Figure 1 is the 23 states observed in the region of astrophysical interest defined by the two double-dotted dashed lines in Figure 1 ($E_{\mathrm{x}} \approx$ 9.8 - 13.8 MeV). These are candidate states for resonances for the ^{44}Ti$(\alpha,p)^{47}$V reaction. However, these states have for now only been identified in energy and their properties such as spin-parity, and branching ratios are still to be determined.

The data from the coincident proton decays from ^{48}Cr excited states are now under analysis. States concealed by the broad contaminants in the region of astrophysical interest can be identified from the decays measured by the CAKE. From these data, spin and parity of the measured states can be extracted. This additional information on the level density and how it compares to the assumption of statistical models will be extracted. The data will also provide insight into how the branching ratio into different final ^{47}V states varies with excitation energy, thereby constraining the ^{44}Ti$(\alpha,p)^{47}$V reaction.

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References
[1] Grefenstette B et al. 2014 *Nature* **504** 339-342
[2] Subedi S, Meisel Z and Merz G 2020 *Astrophys. J.* **898** 5
[3] Magkotsios G et al. 2010 *Astrophys. J. Suppl. Ser.* **191** 66–95
[4] The L S et al. 1998 *Astrophys. J.* **504** 500–515
[5] Chipps K et al. 2020 *Phys. Rev. C* **102** 035806
[6] Sonzogni A A et al. 2000 *Phys. Rev. Lett.* **84** 1651
[7] Margerin V et al. 2014 *Phys. Lett.* B **731** 358 - 361
[8] Magkotsios G et al. 2010 *Astrophys. J.* **191** 66
[9] Neveling R et al. 2011 *Nucl. Instrum. Methods Phys. Res.* A **654** 29-39
[10] Chipps K et al. 2010 *Phys. Rev. C* **82** 045803
[11] Brümmer J W et al. 2023 *Phys. Rev. C* **107** 055802
[12] Adsley P et al. 2017 *J. Instrum.* **12** T02004–T02004
[13] Dorenbusch W E et al. 1973 *Phys. Lett.* B **37** 173-176