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High-Precision Proton-Capture Q Values for ^{25}Al(p,γ)^{26}Si and ^{30}P(p,γ)^{31}Si

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The masses of astrophysically relevant nuclei, ^{25}Al and ^{30}P, have recently been measured with the JYFLTRAP double Penning trap at the new IGISOL-4 facility at the University of Jyväskylä. Unparalleled precisions of 63eV and 64eV were achieved for the ^{25}Al and ^{30}P masses, respectively. The proton-capture Q values for ^{25}Al(p,γ)^{26}Si and ^{30}P(p,γ)^{31}S were also determined, and their precisions improved by a factor of 4 and 2, respectively, in comparison with AME12. The impact of the more precise values on the resonant proton-capture rate has also been studied.

KEYWORDS: atomic masses, Penning-trap mass spectrometry, novae

1. Introduction

The observation of 1809 keV gamma-rays from the beta decay of ^{26}Al ground state is one of the direct proofs of the ongoing nucleosynthesis in the universe [1]. The distribution of ^{26}Al in the Galaxy has shown a dominant concentration around massive star and supernovae but also a contribution from classical novae. The production of ^{26}Al ground state can be bypassed by the proton capture of ^{25}Al, leading to the production of the 0^+ isomeric state in ^{26}Al. To estimate the contribution of novae to the galactic ^{26}Al γ-rays, it is important to know the proton-capture rate for ^{25}Al(p,γ)^{26}Si reaction sequence. The mass of ^{26}Si has already been precisely measured with the JYFLTRAP double Penning trap [2] and the uncertainty on the reaction Q value has been restricted by the mass of ^{25}Al.

The ONe novae are a particular type of novae where ONe white dwarf accretes material from its companion star which eventually leads to an explosion. The higher temperatures reached in ONe novae allow the production of elements heavier than Sulphur through the reaction ^{30}P(p,γ)^{31}S. The ^{30}P(p,γ)^{31}S reaction rate has a strong effect on the ^{30}Si abundance relevant for the final abundance ratios in novae ejecta and therefore also for identifying presolar grains with nova origin. The proton-capture Q value has been limited by the uncertainty in the ^{30}P mass since ^{31}S has already been precisely determined with JYFLTRAP [3].

2. Experiment and results

2.1 Experiment

A 40-MeV proton beam from the K-130 cyclotron was used to produce ^{25}Al and ^{30}P via fusion-evaporation reactions on thin Si and ZnS targets, respectively. The secondary beam was accelerated to 30 keV and the mass number A of the isotopes of interest was selected using a 55° dipole magnet. A radio frequency ion cooler and buncher (RFQ) [4] decelerated the continuous beam and released the ions as short bunches into the double Penning trap JYFLTRAP [5].

The time-of-flight ion-cyclotron method (TOF-ICR) [6,7] was used for the high precision mass measurements of ^{25}Al and ^{30}P. The ions in resonance gain more energy, and reach the Micro Channel Plate (MCP) detector at the end of the beamline faster, and thus their cyclotron resonance frequency can be determined from the TOF-ICR spectrum (Fig.1 and 2). From the precise determination of the cyclotron frequency we obtain the mass of the ion of interest via:

$$\nu_c = \frac{qB}{2\pi m} \qquad (1)$$

where ν_c is the cyclotron resonance frequency, q the charge of the ion (typically singly-charged ions are used at JYFLTRAP), B the magnetic field and m the mass of the ion. The magnetic field B is determined by doing similar measurements with a reference ion whose mass is already well known. In this experiment, ^{25}Mg^{+} and ^{30}Si^{+} ions were used for ^{25}Al^{+} and ^{30}P^{+} ions, respectively.

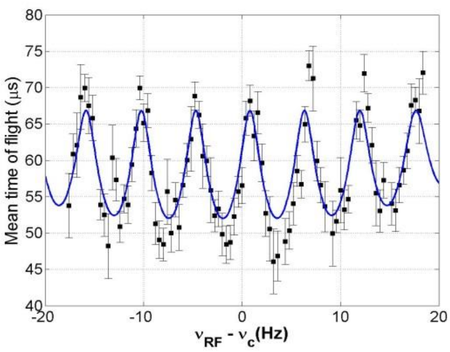

Fig.1. Time-of-flight ion-cyclotron spectrum for ^{25}Al^{+} ions.

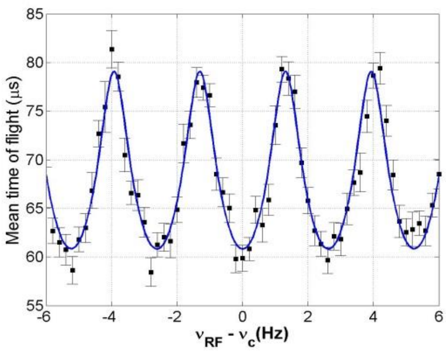

Fig.2. Time-of-flight ion-cyclotron spectrum for ^{30}P^{+} ions.

2.2 Results and comments

The precision of the mass-excess value for ^{25}Al (see Table I) was improved by a factor of 7 in comparison with the AME2012 [8] value. By using the AME2012 mass value for ^{26}Si, based on a previous JYFLTRAP measurement [2], we obtain a proton-capture Q value of 5513.99(13) keV for ^{25}Al(p,γ)^{26}Si. This is 0.2 keV higher than in AME12 (Q(p,γ)=5513.8(5) keV [8]) and almost 4 times more precise.

Table I. The mass-excess *Δ*, the electron-capture Q value Q_{EC} and the proton-capture Q value $Q_{(p,\gamma)}$ in keV obtained at JYFLTRAP compared with AME2012

Ion	^{25}Al	^{30}P
Δ	−8915.962(63)	−20200.854(64)
Δ_{AME12}	−8916.2(5)	−20200.6(3)
Q_{EC}	4276.805(45)	4232.106(60)
$Q_{EC,AME12}$	4276.6(5)	4232.4(3)
$Q_{(p,\gamma)}$	5513.99(13)	6130.64(24)
$Q_{(p,\gamma),AME12}$	5513.8(5)	6130.9(4)

The mass-excess value obtained for ^{30}P reached a precision of 64 eV which is 5 times more precise that for the value given in AME2012 [8]. The proton-capture Q value for the ^{30}P(p,γ)^{31}S reaction has now been determined with an unparalleled precision of 240 eV. The new $Q_{(p,\gamma)}$ value was used to compute the proton-capture resonant rate for the dominant states in ^{26}Si and ^{31}S at typical nova temperatures [9].

3. Conclusion

Proton-capture Q values for ^{25}Al(p,γ)^{26}Si and ^{30}P(p,γ)^{31}S have been precisely determined with the JYFLTRAP double Penning trap at the IGISOL-4 facility. The improved precisions in the proton-capture Q values have reduced the mass-related uncertainties in the reaction rates by ≈ 15% compared to the AME2012. More accurate proton capture rates are useful for future calculations for the production of ^{26}Al and nucleosynthesis in novae.

Acknowledgment

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References

[1] C. Iliadis: *Nuclear Physics of Stars* (Wiley-Vch, Weinheim, 2007) Chap.1, p.8.
[2] T. Eronen *et al.:* Phys. Rev. C **79** (2009) 032802.
[3] A. Kankainen *et al.*: Phys. Rev. C **82** (2010) 052501.
[4] A. Nieminen *et al.*: Nucl. Instrum. Methods Phys. Res. A **469** (2001) 244.
[5] T. Eronen *et al* :, Eur. Phys. J. A **48** (2012) 46.
[6] G. Gräff, H. Kalinowsky and J. Traut : Z. Phys. A **297** (1980) 35.
[7] M. König *et al.*: Int. J. Mass Spectrom. Ion Process. **142** (1995) 95.
[8] M. Wang *et al*.: Chin. Phys. C **36**, (2012) 1603.
[9] L. Canete *et a*l.: Eur. Phys. J. A **52** (2016) 124.