EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Resonant proton scattering of ^{22}Mg

Addendum to IS512

J. Cederkall[1], D. Di Julio[1], C. Fahlander[1], P. Golubev[1], D. Rudolph[1], H. Fynbo[2], T. Nilsson[3], M. J. G. Borge[4], O. Tengblad[4] and N. Imai[5]

[1] Physics Department, Lund University, SE-221 00, Lund, Sweden
[2] Inst. For Fysik og Astronomi, Aarhus University, Aarhus, Denmark
[3] Physics Department, Chalmers University of Technology, Gothenburg, Sweden
[4] Instituto de Estructura de la Materia, CSIC, Madrid, Spain
[5] IPNS, KEK, Japan

Spokesperson: J. Cederkall (Joakim.Cederkall@nuclear.lu.se)
Local contact: M. Kowalska (Magdalena.Kowalska@cern.ch)

Abstract

In our proposal for experiment IS512 we discussed the physics case for scattering and transfer reactions involving light nuclei in the break-out region of the rp-process. The committee supported the proposal and approved beam time for the ^{21}Na case as a starting point. The experiment was recently carried out and analysis is ongoing. We therefore submit this addendum to ask for approval of beam time for the ^{22}Mg case for an experiment in 2015. The purpose is to study resonant proton scattering of ^{22}Mg to identify states in ^{23}Al.

Requested shifts: 15 shifts in 1 year

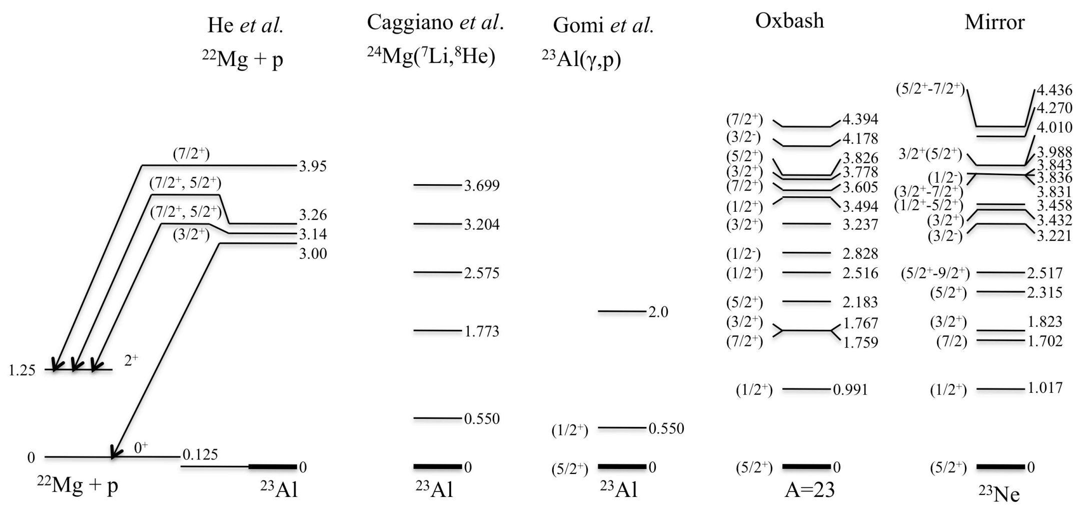

Figure 1. The level structure of ^{23}Al from proton scattering, ^{24}Mg(^{7}Li,^{8}He) and Coulomb dissociation. A theoretical A=23 scheme together with the level scheme of the mirror nucleus ^{23}Ne are given to the right [12].

Introduction

This addendum reiterates the physics case we made for proton scattering in the proposal of experiment IS512. An edited version of the text is repeated here for the committees convenience.

The thermonuclear runaway of the rp-process that is thought to drive novae and X-ray bursters has been discussed in several reviews [1,2,3] after this process was first introduced by Wallace and Woosley [4]. In brief, mass flow onto the surface of a white dwarf or neutron star with remnant seed nuclei should be able to create the conditions needed for an explosive scenario. Typical temperatures and densities for this to occur have been suggested to be in the range; T~ 0.1- 1 GK and $\rho \sim 10^2 - 10^6$ g/cm^3 where the higher values are reached for mass transfer to a neutron star and are believed to trigger X-ray bursts. Calculations indicate that the full process may proceed as far as to mass A~100 [5]. A major question for the rp-process is which reaction path it will follow to avoid stagnation in mini-networks in the region of the light Ne and Na isotopes. Here, one aim has been to predict the amount of monoenergetic γ-rays that can be emitted by proton rich material after freeze out. If such γ-rays are produced they could potentially be used as a signature of proton rich nucleosynthesis in certain astrophysical objects. The idea is similar to the observation of localized monoenergetic γ-rays observed in Cas A and GRO J0852-4642 [6]. In the rp-process case it has been suggested to use the 1.275 MeV line in ^{22}Ne for this purpose. A similar topic is also the mapping of the galactic distribution of ^{26}Al [7]. Yet another motivation for nuclear reaction studies in the break-out region is to understand the power generation well enough to be able to reproduce the explosive process in full.

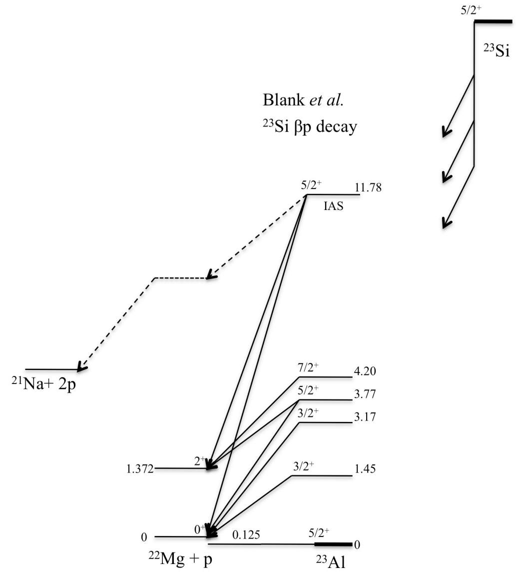

Figure 2. Decay pattern following β-emission of ^{23}Si.

Here connections can be made with observed light curves [8] which is one aim of X-ray burst simulations [9]. In the lighter mass region significant effort has been put into determining the rates of the ^{17}F(p,γ)^{18}Ne [10] and ^{21}Na(p,γ) [11] reactions by direct measurement. However, the picture is still far from clear and many other reaction rates are still missing in order to have network calculations based on experimentally deduced quantities.

The experiment proposed here focusses on determining the structure above proton threshold for ^{23}Al. The ^{22}Mg(p,γ) ^{23}Al reaction has not been measured directly yet and it is therefore of interest use other methods to establish a full picture of its level structure. Although the proton separation energy is low (~125 keV) proton capture on this isotope provides a way to bypass the β-decay to ^{22}Ne mentioned above. As of yet only one attempt has been made to populate proton resonances in ^{23}Al but unfortunately only states above ~3 MeV were seen in that study [12]. Thus, with the current experiment we propose to scan for states below this energy. Here one can note that βp and βpp decay studies involving ^{23}Si have also been carried out [13].

The structure of ^{23}Al

The ground state

The ground state spin and parity has been determined using β-NMR to $5/2^+$ [14].

The 550 keV state

At least three attempts have been made to populate states in ^{23}Al using the ^{24}Mg(^{7}Li,^{8}He) reaction. Wiescher et al. published the first evidence for a state in ^{23}Al using this reaction at

191 MeV at NSCL [15]. The state remained unresolved from the ground state and the energy was given as 470 ± 40 keV (proton threshold 125 keV). This value was an averaged value including a reanalysis of an experiment by Benenson *et al.* [16]. A follow-up experiment was carried out by Caggiano *et al.* [17] in 2001 using a ^{7}Li beam at 50.1 MeV/u and a resolved peak at 550 keV was observed (see Fig. 1). The corresponding state in the mirror ^{23}Ne is at ~1 MeV. The lower energy for the state in ^{23}Al is attributed to a Thomas-Ehrman shift supposedly due to pronounced single particle structure. Caggiano *et al.* calculated the proton width to be 74.0 eV. This width differed by a factor of 2 from the one previously published by Wiescher *et al.* In 2005 Gomi *et al.* [18] did Coulomb dissociation of ^{23}Al at 50 MeV/u and published a value of $\Gamma_\gamma = 7.2 \cdot 10^{-7}$ eV. This value was well in line with the value predicted by Caggiano *et al.*, $\Gamma_\gamma = 5.5 \cdot 10^{-7}$ eV. The assumption is that the state has spin and parity $1/2^+$. The capture is predicted to proceed via this state and directly to the ground state with about the same rate for T = 0.4-0.8 GK. According to current knowledge the direct capture dominates below and above this temperature.

Higher lying states from ^{24}Mg(^{7}Li,^{8}He)

Caggiano *et al.* also observed a state at 1.773 MeV while this state was not observed by Gomi *et al.* The width of the state has been estimated to ~ 1 keV. The state at 2.575 MeV is speculated to correspond to the first $5/2^+$ predicted by theory. The width of this state for decay to the ground state in ^{22}Mg has been calculated to be ~ 3 keV while the decay to the the first excited state at 1.25 MeV may be 20 keV [12]. According to theory there are thus only two states below this energy that could fit the 1.773 MeV state. These have spin and parity $7/2^+$ and $3/2^+$, respectively. One can note that the level at 2.0 MeV for the study of Gomi *et al.* given ref. [12] is not discussed in ref. [18].

States observed in proton scattering

An interesting result of the first resonant scattering experiment described in ref. [12] is that no states were observed below 3.0 MeV. The experiment was carried out at CNS at RIKEN using the ^{3}He(^{22}Ne,^{22}Mg)n reaction producing a 4.38 MeV/u beam of $4.4 \cdot 10^4$ pps with a purity of 3% and an energy spread of 0.18 MeV/u. The beam spot was 15 × 11 mm. These factors may have influenced the possibility to observe weaker resonances. The state at 3.0 MeV is identified as the theoretical second $3/2^+$ state (see Fig. 1). The predicted width of the state is 44 keV, close to the observed 32± 5 keV.

States observed in βp

Blank *et al.* [13] have performed proton spectroscopy following β –decay of ^{23}Si. In short, decay from the IAS to the ground state and the 2^+ state in ^{22}Mg was observed. Proton lines corresponding to the assumed decay of excited states in ^{22}Mg with spins $3/2^+$ - $7/2^+$ were assigned but the assignment was not firm.

The experimental set up.

The new scattering chamber mentioned in the original proposal was used in two experiments in 2012. The detector system consists of a number Double Sided Silicon strip detectors (DSSSDs) that can be mounted at different distances and angles from the target. They are transmission mounted and can be used in telescope configurations for particle identification. The detector system was also described earlier.

Targetry

Sufficient yields of ^{22}Mg has been produced using SiC targets at ISOLDE already at the SC. The yield book states a ^{22}Mg yield of 8.8E5 p/μC. The main issue for the Mg beam has been the purity (the lifetime is 3.9 s). The development of the beam has been on the priority list of the upgrade group. Recent tests have concluded that a full stripping of ^{22}Mg should be possible using a thin carbon foil with an efficiency of 10%. The contaminating Na isobar is then separated from the beam in the analyzing magnet before the target station. With a post acceleration efficiency, without stripping, of ~10% the yield will be ~1E4 p/μC after stripping which is sufficient for a scattering experiment.

Summary

We propose to perform resonant proton scattering using beams of ^{22}Mg to study resonant states in ^{23}Al as discussed above.

Summary of requested shifts:

We request 15 shifts for the ^{22}Mg beam including 3 shifts for beam set up.

References:

[1] G. Wallerstein *et al.,* Rev. Mod. Phys. 69, 995 (1997)

[2] H. Schatz *et al.,* Physics Reports 294, 167 (1998)

[3] C. Bertulani and A. Gade, Physics Reports 485, 195 (2010)

[4] R. K. Wallace and S. E. Woosley, Astrophys. J. Suppl. 45, 389 (1981)

[5] H. Schatz *et al.,* Phys. Rev. Lett. 86, 3471 (2001)

[6] A. F. Iyudin *et al.* Nature 396, 142-144 (1998) and references therein.

[7] R. Diehl *et al.,* Astron. and Astrophys 298, 445 (1995)

[8] D. K. Galloway *et al.,* Astrophys. J. 601, 466 (2004)

[9] S. E. Woosley *et al.*, Astrophys. J. suppl. 151, 75 (2004)

[10] K. A. Chipps *et al.*, Phys. Rev. Lett. 102, 152502 (2009) and references therein.

[11] S. Bishop *et al.,* Phys. Rev. Lett. 90, 162501 (2003) and references therein.

[12] J. J. He *et al.*, Phys. Rev. C. 76, 055802 (2007)

[13] B. Blank *et al.*, Z. Phys. A. 357, 247 (1997)

[14] A. Ozawa *et al.,* Phys. Rev. C 74, 021301 (R) (2006)

[15] M. Wiescher *et al.* Nucl. Phys. A 484, 90 (1988)

[16] W. Benenson *et al.* Phys. Lett. B 58, 46 (1975)

[17] J. A. Caggiano *et al.* Phys. Rev. C 64 025802 (2001)

[18] T. Gomi *et al.* Nucl. Phys. A 758, 761c (2005)

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises:

Part of the Choose an item.	Availability	Design and manufacturing
Scattering chamber. In place since 2010.	☒ Existing	☒ To be used without any modification
		A vacuum chamber and a set of silicon strip detectors. Pumps for vacuum. Electronics for data acquistion. Voltage supplies for detectors. All standard equipment.
[Part 1 of experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH] installation.

Additional hazards:

Hazards	*[Part 1 of the experiment/equipment]*	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	No		
Vacuum	1E-6 mbar		
Temperature	No (room temperature)		
Heat transfer	No		
Thermal properties of materials	No		
Cryogenic fluid	None		
Electrical and electromagnetic			
Electricity	[50] [V], [1E-6][A]*6		
Static electricity			
Magnetic field	none [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	(CH2)n (Polyethylene plastic)		
Beam particle type (e, p, ions, etc)	22Mg and 21Na		

Beam intensity	~10E4 pps		
Beam energy	3 MeV/u		
Cooling liquids	No		
Gases	No		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:	No		
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser	No		
UV light	No		
Microwaves (300MHz-30 GHz)	No		
Radiofrequency (1-300MHz)	No		
Chemical			
Toxic			
Harmful			
CMR (carcinogens, mutagens and substances toxic to reproduction)			
Corrosive			
Irritant			
Flammable			
Oxidizing			
Explosiveness			
Asphyxiant			
Dangerous for the environment			
Mechanical			
Physical impact or mechanical energy (moving parts)	No		
Mechanical properties (Sharp, rough, slippery)	No		
Vibration	No		
Vehicles and Means of Transport	No		
Noise			
Frequency	No		
Intensity	No		
Physical			
Confined spaces	No		
High workplaces	No		
Access to high workplaces	No		
Obstructions in passageways	No		
Manual handling	No		
Poor ergonomics	No		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

4 crates with 500 W power supplies