TRIUMF — RESEARCH PROPOSAL

Experiment no.

927*

Title of proposed experiment:

Spectroscopy of ^{22}Mg using (^{3}He,p)

Name of group: TUDA

Spokesperson for group: F. Sarazin / L. Buchmann

E-Mail address: sarazin@triumf.ca , lothar@triumf.ca Fax number:

Members of the group (name, institution, status, per cent of time devoted to experiment)

Name	Institution	Status	Time
M-L. Aliotta	Univ. Edinburgh	Assistant Professor	10%
J. D'Auria	Simon Fraser University	Professor	20%
G. Ball	TRIUMF	Senior Research Scientist	10%
L. Buchmann	TRIUMF	Senior Research Scientist	30%
A. Chen	Univ. McMaster	Assistant Professor	10%
T. Davinson	Univ. Edinburgh	Research Scientist	10%
S. Fox	Univ. York	Research Officer	10%
B. Fulton	Univ. York	Professor	10%
U. Greife	Colorado School of Mines	Associate Professor	20%
D. Groombridge	Univ. York	Research Fellow	10%
G. Hackman	TRIUMF	Research Scientist	10%
C. Jewett	Colorado School of Mines	Graduate Student	50%
A. Laird	Univ. York	Assistant Professor	20%
A. Murphy	Univ. Edinburgh	Assistant Professor	10%
F. de Oliveira	GANIL	Research Scientist	10%
J. Pearson	Univ. York	Graduate Student	10%
R. Pitkin	Univ. York	Graduate Student	10%
E. Rehm	Argonne National Laboratory	Research Scientist	20%
I. Roberts	Univ. Edinburgh	Graduate Student	10%
C. Ruiz	TRIUMF	Research Associate	20%
F. Sarazin	Colorado School of Mines	Assistant Professor	30%
A. Shotter	TRIUMF	Professor	10%
C. Svensson	Univ. Guelph	Assistant Professor	10%
J. Waddington	Univ. McMaster	Professor	10%
P. Walden	TRIUMF	Senior Research Scientist	20%
P. Woods	Univ. Edinburgh	Professor	10%

Start of preparations:	July 2002
Date ready:	October 2003
Completion date:	April 2004

Beam time requested:

12-hr shifts	Beam line/channel	Polarized primary beam?
8	TUDA @ ISAC	No

Note: this is an addendum to the proposal #927.

We propose to use the ^{20}Na(^{3}He,p)^{22}Mg reaction in inverse kinematics to investigate the spectroscopy of ^{22}Mg and especially look for possible unobserved states in the astrophysically relevant 5-7 MeV excitation region.

BEAM REQUIREMENTS	Expt # 927*	Sheet 3 of 10

Experimental area

ISAC-HE, TUDA

Primary beam and target (energy, energy spread, intensity, pulse characteristics, emittance)

SiC, 500 MeV, cw
Surface Ion Source

Secondary channel ISAC-HE

Secondary beam (particle type, momentum range, momentum bite, solid angle, spot size, emmittance, intensity, beam purity, target, special characteristics)

^{20}Ne (stable) for set-up, Max. 1.64 MeV/u
^{20}Na (unstable) up to 10^8 pps, Max. 1.64 MeV/u

TRIUMF SUPPORT:

No unusual support required

NON-TRIUMF SUPPORT

The TUDA facility, including considerable manpower for setup and operation, is provided by U. of Edinburgh and U. of York. The TUDA collaboration is supported by a NSERC grant for manpower, replacement parts and computing support. The He gas cell will be provided by Argonne National Laboratory.

Standard TUDA operation with short lived radioactive isotopes, (^{20}Na, $T_{1/2}$= 448ms). Low voltage detectors and electronics.Gas target.

1 Scientific Justification

The Carbon-Nitrogen-Oxygen (CNO) cycles are thought to be the main source of energy generation in novae and X-ray bursts in their ignition phase [1]. Under certain extreme conditions of temperature and density, these cycles may be broken by so-called breakout reactions such as $^{15}O(\alpha,\gamma)^{19}Ne(p,\gamma)^{20}Na$ or $^{18}Ne(\alpha,p)^{21}Na$, which link the CNO cycles to the rp-process, a long sequence of proton captures and beta-decays towards higher masses. Precise knowledge of the structure of a few states above the relevant particle threshold in the compound nuclei is required to calculate the rate of the reactions involved in the breakout of the CNO cycles and in the subsequent rp-process.

The first experiment on the DRAGON facility was a measurement of the rate of the $^{21}Na(p,\gamma)^{22}Mg$ reaction in an energy regime of importance for novae and possibly X-rays bursts in explosive stellar scenarios. This involved levels in ^{22}Mg from proton threshold to excitation energy of about 6.3 MeV (see Fig. 1). This reaction is important as it plays a significant role in the production of ^{22}Na in the universe; the latter can be observed using gamma ray telescopes and is a benchmark for our understanding of the mechanism of novae explosions.

Radiative proton capture in this energy regime involves resonance reactions and it is very important to know the energy of such resonance before studies involving relatively low intensity radioactive beams are possible. In fact the levels of ^{22}Mg were studied in detail prior to the RB experiment, using a (p,t) reaction elsewhere [2] and these are shown below. Several other similar studies have also been performed and based upon all of these studies and the studies with DRAGON, it can be stated fairly clearly that the level shown at 5.837 MeV does not exist. Recent studies by B. Davids et al [3] and S. Michimasa et al. [4] seem to indicate that the states at 5.9 and 6.0 MeV are probably low spin states, 0,1. The state at 5.7 MeV is known to be a 2^+ state while the spin of the state at 6.2 MeV could be a high spin state perhaps.

The present situation is that the resonance strengths of all of the resonances shown in the figure have been measured using DRAGON [5] and the rate of the reaction at nova temperatures has been estimated. However, upon inspection of the levels in the analogue nucleus, it does suggest that there may be additional states that have not yet been observed in ^{22}Mg. For example, the state at 5.8 MeV was thought to be a high spin state and now has been discounted. The purpose of proposing this study of the (^{3}He,p) reaction is to perform an additional study of and search for any states not previously observed, lying in region of possible astrophysics interest, e.g. E_{cm}~0.1-0.7 MeV. The previous studies of this nucleus mainly focused on studies using the (p,t) reaction and the (^{3}He,n) reaction. It is possible that a (^{3}He,p) reaction may populate different states. It should be noted that a similar rationale is being proposed to study products of a heavy ion fusion, xn reaction at ANL using Gammasphere. In this latter study the branching ratio of the various states will also be studied. Following the observation of any new states, an attempt will be to measure the radiative proton capture using at beam of ^{21}Na but at the new resonance energy.

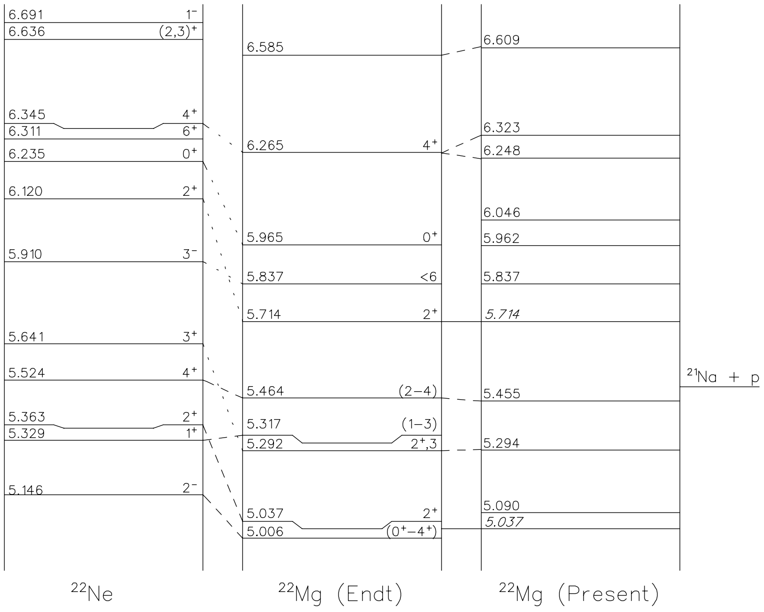

Fig. 1 Known levels in ^{22}Mg and its mirror nucleus ^{22}Ne in the 5-7 MeV region and the suggested pairing between mirror states.

2 Description of the Experiment

2.1 The (^{3}He,p) transfer reaction

We propose to use the (^{3}He,p) reaction in inverse kinematics at the TUDA scattering chamber [6] at ISAC-I as an alternative to elastic scattering. For proton-rich nuclei this reaction has a high Q-value, which allows the population of a wide range of states with a single beam energy.

At ISAC-I energies (maximum 1.64 MeV per nucleon), the deuteron transfer is expected to proceed mainly (but not exclusively) via a compound nucleus mechanism as it has been reported for the nearby reaction ^{20}Ne(^{3}He,p)^{22}Na at 2.8 and 3 MeV [7]. They also report the observation of states with spins as high as 5^+, which shows that large L-transfers are possible although with a small cost in cross-section. It is therefore a suitable reaction to populate excited states rather indiscriminately, which can be a clear advantage compared to resonant elastic scattering.

Estimates of the cross section will be discussed in the appropriate section of the proposal.

2.2 The ^{3}He gas target

The gas target will consist of a 5mm thick ^{3}He LN$_2$-cooled gas cell at a pressure of about 500 mbar and the entry foil of a 1mg/cm^2 Ni foil. Low Z foils (Polypropylene,Kapton) are being studied in Argonne National Laboratory to reduce the energy loss and straggling in the entry foil. If the tests are proved succesful, these foils would be used instead of the present Ni foils. The target has been designed, built and already used for experiments [8] or secondary beam production [9] at Argonne National Laboratory. The clear advantage of such a cold target is that for a same pressure, it contains more ^{3}He atoms/cm^2 than at room temperature. Therefore, it allows the target to be thinner, enabling better energy resolution. When the time comes, it would be shipped to TRIUMF and fitted to the TUDA chamber for the experiment. A new flange supporting the target and including ^{3}He and LN$_2$ feed-throughs is being designed and built at TRIUMF and will be fitted to the chamber by the end of the summer. A gas handling system is already in place underneath the TUDA experimental chamber.

2.3 Spectroscopy ^{22}Mg

As discussed in the scientific motivations, it is possible that one or more states may remain to be observed in the 5-7 MeV region of interest in ^{22}Mg. The (^{3}He,p) transfer reaction at maximum beam energy is particularly well suited to probe this region because of its large Q-value of 14.88 MeV. With such a high Q-value, protons are emitted in both forward and backward hemispheres. While the energy of the protons emitted in the forward hemisphere are well over the detection capability of our present setup, the energy of the ones emitted in the backward direction cover nicely the range of energy that could be detected by two 300μm LEDA, placed upstream at 10 cm from the entrance of the target, mounted back to back (up to 9 MeV protons). In order to have a better angular resolution, the stack of two LEDA detectors could be mounted such that each LEDA sector of the back detector is offset from its corresponding sector in the front detector by half a strip size in the radial direction. This results in having twice the resolution of a LEDA detector over most of its surface ("Super-LEDA" configuration). In these optimal conditions, almost every states known in the 5-7 MeV region could be resolved as shown by a monte-carlo simulation in Fig. 2. Evidence of new states, if populated, in this region could be obtained from a careful analysis.

Two HPGe detectors will be placed around the target position. By analysing p-γ coincidences, one would be able to observe the γ-decay of excited states in ^{22}Mg. We would particularly focus on the astrophysically relevant states in the 5-7 MeV region. Although, in this first experiment, we do not intend to measure the γ branching ratios of these states, we could nevertheless observe some p-γ coincidences arising from states above the ^{21}Na+p threshold.

Beside the possible observation of new states in ^{22}Mg, which is the main goal of this experiment, an additional detailed spectroscopy of ^{22}Mg should be obtained.

3 Experimental Equipment and Readiness

As reported before, the TUDA facility has been fitted with a gas handling system, which will allow the gas cell to be kept at a constant pressure. A new flange is being designed to support the gas cell and feedthroughs. Two 300μm thick LEDA detector are already available. Depending on its availability, the TIGRESS prototype clover could be used for its first in-beam experiment. However, for this experiment, it is not likely that

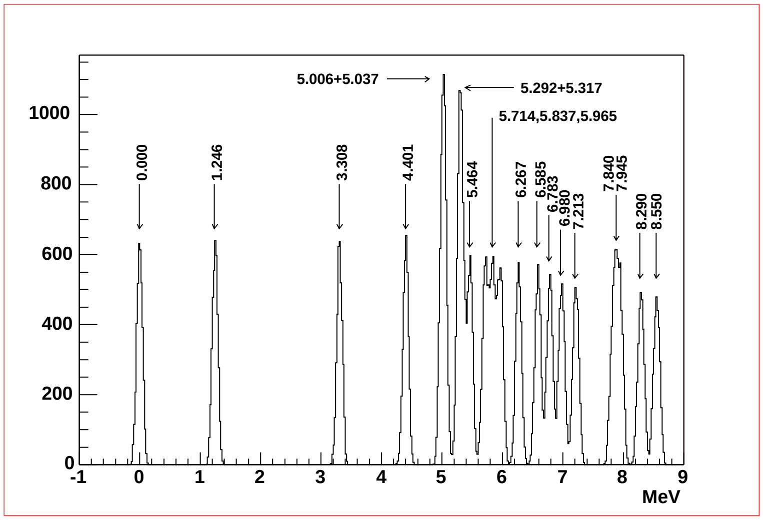

Fig. 2 Simulation of the reconstruction of the excitation energy of ^{22}Mg from the protons detected in a LEDA detector located 10 cm upstream from the target. In this simulation, every state had an equal probability to be populated to show only the geometric efficiency of the experimental setup and the achiveable discrimination between the excited states.

the branching ratios of new states above the ^{21}Na+p treshold could be measured. A more classic HPGe could give valuable information of the γ background observed in (^{3}He,p) experiment and therefore would be of interest in order to plan further experiments that would require γ-ray detection. Provided that this experiment is approved, it should be ready to run by October 2003.

4 Beam Time required

The yield of ^{20}Na has been measured to be up to 2×10^{8} ^{20}Na per second from a SiC target (Nov.2002). From systematics, it is reasonable to estimate that the expected cross section for the reaction will be of the order of 0.1mb per state. With a target of 10^{19} atoms per cm^{2} thickness of ^{3}He and about 7% (cm) of solid angle covered by the particle detection system, we expect about 50 events/hour/state.

This experiment is ideal for a first (^{3}He,p) radioactive beam experiment. Eight shifts should provide enough statistics to look for new excited states in ^{22}Mg and obtain a significant amount of p-γ coincidences. Prior to the radioactive beam time, we request at least 3 shifts of stable ^{20}Ne beam to test the experimental setup. It should be mentioned that the availability of the cryogenic ^{3}He target might be subject to a tight schedule due to its use at Argonne Nat. Lab.

References

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