TRIUMF — RESEARCH PROPOSAL	Experiment no. 879	Sheet 1 of 20

Title of proposed experiment:

Proton-^{21}Na elastic scattering at astrophysical energies

Name of group: Napel

Spokesperson for group: L.Buchmann/A.Shotter

E-Mail address: lothar@triumf.ca, acs@ph.ed.ac.uk Fax number: 222-1074

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

R.E.Azuma	U. of Toronto	Professor em.	45%
L.Buchmann	TRIUMF	Senior Research Scientist	30%
A.Chen	TRIUMF/SFU	Research Associate	30%
J.Daly	U. of Notre Dame	Grad. Student	30%
T.Davinson	U. of Edinburgh	Senior Research Fellow	30%
J.D'Auria	SFU	Professor	10%
J.Görres	U. of Notre Dame	Research Professor	10%
J.D.King	U. of Toronto	Professor em.	15%
E.S. Konobeevsky	INR RAS	Senior Research Scientist	20%
M.V. Mordovskoy	INR RAS	Research Scientist	15%
A.Ostrowski	U. of Edinburgh	Professor	20%
F.Sarazin	U. of Edinburgh	Research Fellow	30%
A.Shotter	U. of Edinburgh	Full Professor	30%
V.A.Simonov	INR RAS	Research Scientist	15%
A.V. Stepanov	INR RAS	Professor	10%
M.Wiescher	U. of Notre Dame	Full Professor	20%
P.Woods	U. of Edinburgh	Professor	20%
V.P. Zavarzina	INR RAS	Research Scientist	15%

Start of preparations: now

Date ready: October 2000

Completion date: October 2001

Beam time requested:

12-hr shifts	Beam line/channel	Polarized primary beam?
18 (radioactive)	ISAC-HE	na

It is proposed to measure the proton+^{21}Na elastic scattering reaction in inverse kinematics at the TUDA scattering facility employing a solid polyethylene target. The reason for such a measurement is to explore the state structure of the compound nucleus ^{22}Mg as preparation for the measurement of the radiative capture reaction ^{21}Na(p,γ)^{22}Mg at the DRAGON facility. Such a study is necessary for several reasons: A recent measurement of the ^{24}Mg(p,t)^{22}Mg transfer reaction found a substantially different state structure of ^{22}Mg in the region of interest than quoted in literature. Furthermore, even under optimal conditions it will not be possible for DRAGON to map a full excitation function, therefore the precise knowledge of possible radiative capture resonances is crucial. If a sufficient number of states have been identified, a comparison with shell model calculations and the analog nucleus ^{22}Ne will allow to identify missing states close to threshold not accessible in elastic scattering. In the same measurement, it should be possible to identify inelastic transitions to the E_x=330 keV first excited state in ^{21}Na which (combined with a radiative capture measurement) will allow to conclude the rate of the ^{21}Na*(p,γ)^{22}Mg reaction. To investigate the efficiency of the system and to determine necessary correction factors we propose in addition to measure well known low energy resonances in ^{23}Na(p,γ)^{24}Mg in inverse kinematics in off-line mode.

Experimental area

ISAC-HE, TUDA

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

p-MgO or SiC, 500 MeV, cw

Secondary channel ISAC-HE

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

^{21}Na (unstable) up to 10^8 s^{-1}, 0.4 to 1.5 MeV/u, ^{23}Na (stable), 0.2 to 1.5 MeV/u

TRIUMF SUPPORT:

TUDA services as presented to and reviewed by TRIUMF. This includes an electronics cabin and special grounding.

NON-TRIUMF SUPPORT

The TUDA facility, including considerable manpower for setup and operation, will be provided by U. of Edinburgh group. A NSERC project grant for manpower, replacement parts and computing support has been submitted.

Standard TUDA operation with a short lived radioactive isotope, (^{21}Na, $T_{1/2}$=22.48 s). Low voltage detectors and electronics.

œ

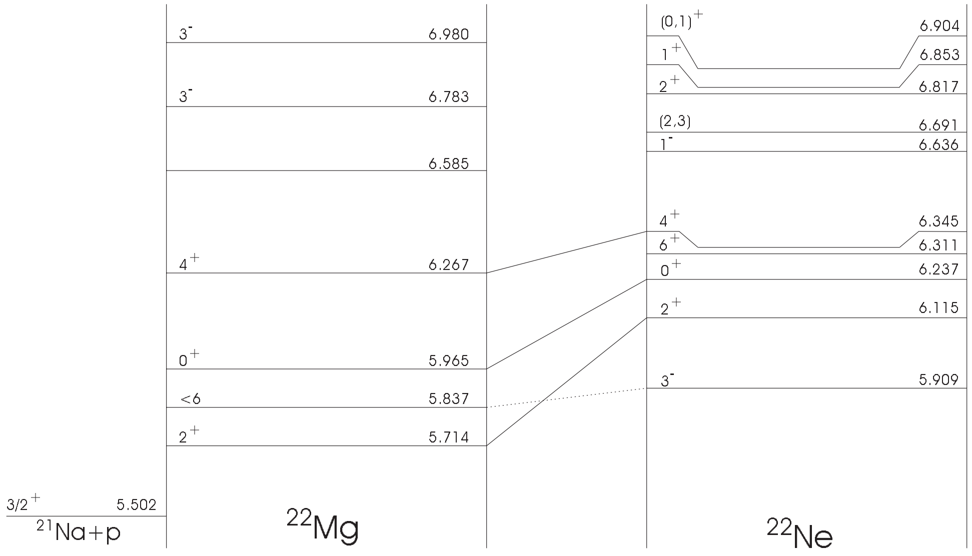


Fig. 1 Level structure of ^{22}Mg close to the ^{21}Na+p threshold and the analog state region in ^{22}Ne from literature [2].

1 Scientific Justification

1.1 Introduction

In recent years there has been considerable interest in nuclear reactions being part of what is labelled the (stellar) rp-process. Identified astrophysical sites for this process are novae and class I X-ray bursters. One of the reactions assumed to play a part in novae and particular the formation (or bypass) of the γ-ray observable, long lived isotope, ^{22}Na is the ^{21}Na(p,γ)^{22}Mg reaction (see references in Ref. [1]). The TRIUMF EEC has approved a measurement of the ^{21}Na(p,γ)^{22}Mg reaction (E824). For efficient running of the radiative capture measurement knowledge of the energy positions of the resonances is important. However, recent measurements indicate that this knowledge is incomplete. The proposed experiment will attempt to improve this knowledge.

1.2 Level structure of ^{22}Mg

Figure 1 shows the level structure of ^{22}Mg close to the ^{21}Na+p threshold and the analog state region in ^{22}Ne as known about two years ago from literature [2]. Possible analog assignment of states between ^{22}Mg and ^{22}Ne are made in figure 1. It may be noted that the positive parity states have a stronger downward shift than the negative ones, and that there are strong J dependences for the positive parity states. Potential proton resonances in ^{21}Na+p system are then possibly found to be at E_R=0.212, 0.336, 0.464, 0.770, 1.088, 1.286 and 1.483 MeV, respectively. However, a couple of the higher lying states in ^{22}Ne have no analog assignment and may be found in the experimental region of interest.

Recently a ^{24}Mg(p,t)^{22}Mg transfer reaction has been performed by parts of our group to reduce the rather large errors on some of the ^{22}Mg excitation energies reported in literature. To our surprise two more states than previously known in the interesting region were found in ^{22}Mg while the existence of a state at E_x=5.837 MeV was not confirmed. One of these is at the astrophysical important energy of E_x=6.046 MeV corresponding to a resonance at 0.545 MeV. It is not clear, if this state or the state at E_x=5.965 MeV are of J^π=0^+ according to analog assignment with ^{22}Ne. The shell model does not predict additional states in this region (of natural parity). It may be pointed out that all transfer reactions leading to ^{22}Mg so far investigated are largely sensitive to natural parity states only. In particular 1^+ states corresponding to *s*-wave capture could be missed.

1.3 Using elastic scattering as a resonance probe

In general, providing the reaction widths are not too small, elastic scattering experiments A(p,p)A provide a valuable probe to study resonance parameters for the A(p,γ)A reaction. Information concerning resonance energies, angular momentum and total widths can be obtained. However, since there are two possible channel spins (s=1 or 2) in the entry channel, the final angular momentum of a state must be derived by other means, normally some nuclear structure arguments, analog assignments, or if known from DRAGON, γ strength arguments. In principle, due to different angular correlation coefficients, the extremely careful measurement of an angular distribution will also allow to determine the spin of the resonance[1]. However, in a first generation experiment we do not expect to achieve such precision.

The J^π=6^+ state in ^{22}Ne state has no obvious partner in ^{22}Mg and is expected to be somewhere between the E_R=0.464 MeV and the E_R=0.770 MeV resonance. It maybe identified with either the E_x=5.965 MeV or the E_x=6.046 MeV state. However, in both cases this would be a rather unusual level shift. A state of J^π=6^+ (ℓ=4) will certainly not show much resonance strength in this energy region. With good resolution the E_R=0.464 MeV, the E_R=0.544 MeV and the E_R=0.770 MeV resonance will be visible in elastic scattering depending on the angular momentum of the entrance channel (see below). Further unnoticed resonances are expected around E_R=1 MeV and higher from analog states in ^{22}Ne. If spin assignments for these states can also be obtained, then this will not only provide valuable information concerning (p,γ), it will also clarify analog assignments in the mirror nucleus ^{22}Ne and yield precision Thomas-Ehrmann shifts.

Between the likely relatively narrow states of ^{22}Mg in the energy region covered, the elastic scattering will test the nuclear potential directly as deviations from hard-sphere scattering can be observed. Indeed broad structures from *s*-wave scattering may be observed as there are two known 1^+ states below threshold and above our energy range. Such an observation will have implications for the estimate of the non-resonant direct capture part of the ^{21}Na(p,γ)^{22}Mg reaction as well as for shell model calculations of this nucleus.

---

[1] Polarized beams would do, of course, too.

1.4 Radiative capture from the first excited state of ^{21}Na

From an astrophysical viewpoint radiative capture for the reaction ^{21}Na(p,γ)^{22}Mg is complicated due to the low first excited state of ^{21}Na with a spin/parity of $J^{\pi}=5/2^{+}$ at E_x=330 keV. This state will be populated in a thermal bath[2] at temperatures around and above 1 GK (X-ray burster). This can also lead to radiative capture from this state. Likely resonances are with the $J^{\pi}=0^{+}$ state at E_x=5.965 MeV or E_x=6.046 MeV excitation and the $J^{\pi}=4^{+}$ state at E_x=6.267 MeV excitation (this state may have a considerable width), unless more states are found in this energy region by elastic scattering. With inelastic proton scattering through these resonances the partial widths of the p_0 and p_1 transitions can be measured. With a knowledge of the γ-resonance strengths for the ^{21}Na ground state transitions it is possible to deduce the stellar reaction rate for proton capture at the first excited state of ^{21}Na as well. A final scattering analysis of wider states at higher energies has to take this additional particle channel into account, as well as the two possible channel spins in each physical channel and multiple angular momenta that can contribute in the population of a specific state.

2 Description of the Experiment

The experiment is planned at the TUDA facility under construction in the ISAC experimental hall. TUDA is a facility which comprises large scale silicon arrays to measure charged particle reactions in inverse kinematics. Figure 2 shows an overview of the facility. The facility is under construction and is expected to be operational by late autumn of 2000, including electronics (256 channels) and data acquisition. For 2001 an upgrade to 512 channels is planned. Event rates of up to 50 kHz will be handled by the data acquisition system. Detectors available to the Edinburgh group are shown in Fig. 2. At present, it is planned to use two LEDA arrays and one CD array, all mounted at forward angles.

We plan to run an excitation function from 0.45 MeV (9.9 MeV) to 1.43 MeV (31.5 MeV) in the centre-of-mass (lab.) system. The plan is to measure solely the recoil protons from the target using background suppression available from the time structure of the beam. In such an experiment the possible angular coverage is given for low lab. angles of the protons (high c.m. angles) by the achievable count rates of background beam (the ^{21}Na nuclei only scatter into 2.7°), for high lab. angles (low c.m. angles) by the ever diminishing energy of the proton towards 90°. With this (assuming a 200 keV detection threshold for the proton) we expect to be able to cover laboratory angles from 10° to 70°, covering about 40° to 160° in the c.m. system. The major background will result from recoil scattering of ^{12}C particles from the polyethylene foil at large angles and the scattering of ^{21}Na on ^{12}C with a maximum opening angle of 35° for low angles.

While the state structure of ^{22}Mg in the region of interest is at least partially known, there is little information about the widths of the states discovered, except for a general upper limit of about 30 keV and one lifetime measurement for the 2^{+} state at 5.714 MeV [3]. To estimate reaction cross sections and the integrative properties of our target, we assume therefore an all over proton dimensionless reduced width of Θ_p=0.1. With an

---

[2] The transition to the $J^{\pi}=3/2^{+}$ ground state of ^{21}Na is of $M1/E2$ nature and therefore not suppressed.

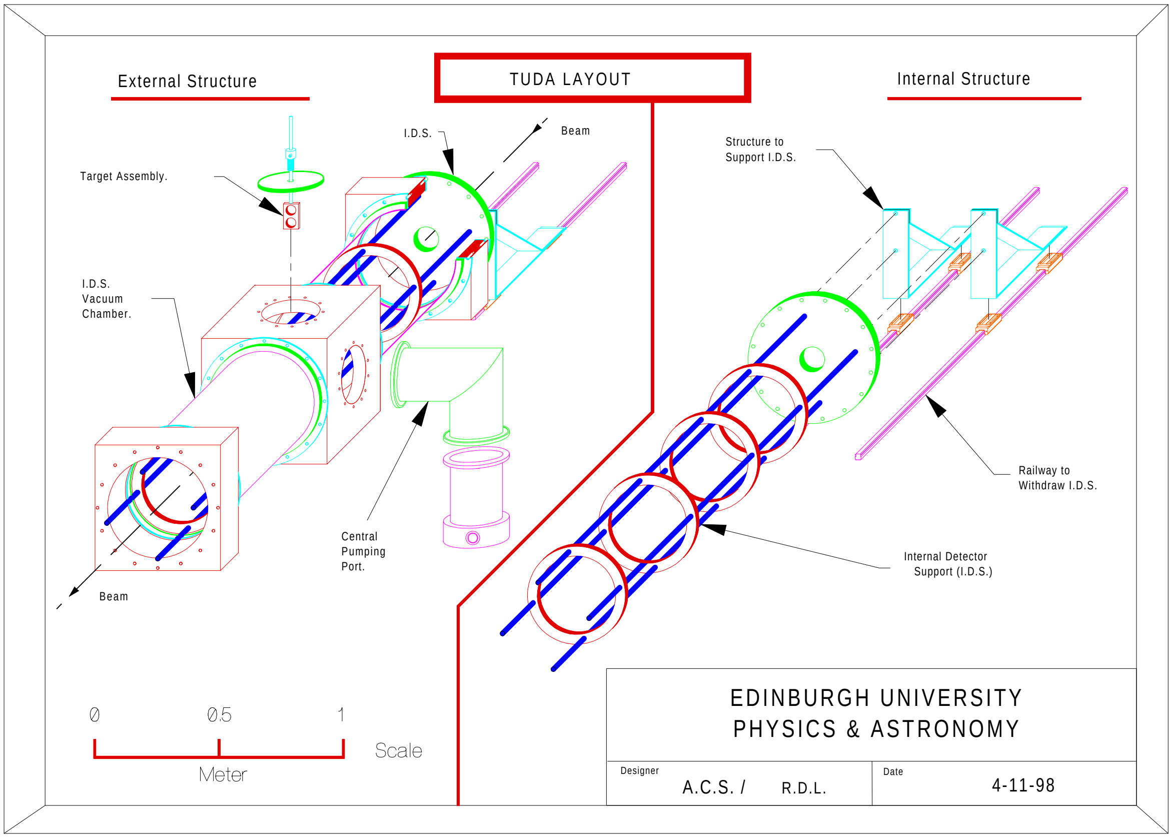
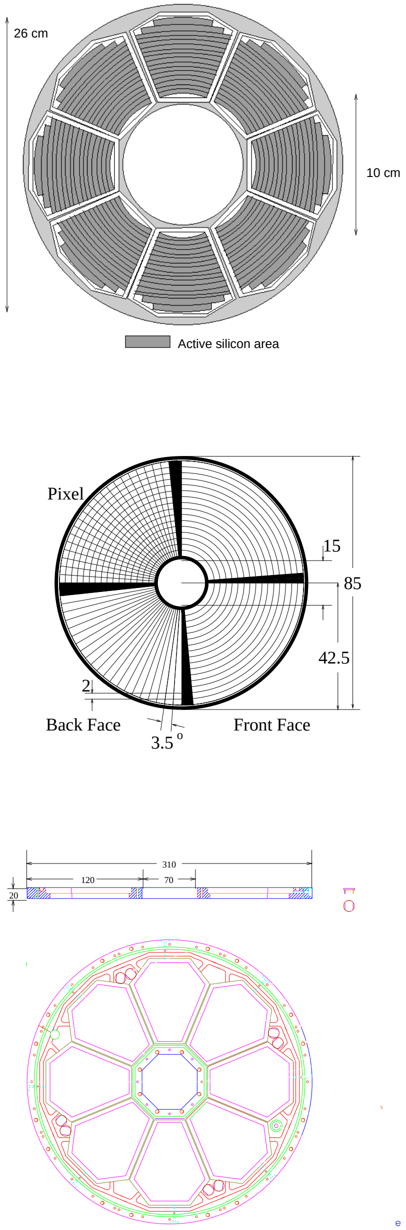


Fig. 2 Overview of the TUDA facility.



The LEDA (top), CD (middle) and SWAN (bottom) detector arrays.

E_x (MeV)	E_R (MeV)	$E_{^{21}Na}$(MeV)	J$^\pi$	ℓ	Γ (keV)^a
5.714	0.212	4.664	2^+	s, d, g	$8.6\times10^{-5\,b}$
5.837	0.336	7.392	3^-	p, f^c	3.7×10^{-3}
5.963	0.461	10.142	0^{+c}	d^c	1.6×10^{-3}
6.047	0.545	11.990	0^{+c}	d^c	$6.1\times10^{-3\ d}$
6.247	0.745	16.390	4^+	d, g	5.8×10^{-2}
6.323	0.821	18.062	1^{-c}	p, f^c	1.2
6.613	1.111	24.442	2^{+c}	s, d, g^c	19
6.753	1.281	28.182	3^-	p, f, h	11
6.980	1.478	32.516	3^-	p, f, h	20

[a] Lowest ℓ assumed.
[b] From Ref. [3]: 1.6×10^{-5} keV.
[c] Assumed value.
[d] For an s wave: Γ=0.41 keV.

Table 1 Resonance properties in ^{21}Na+p and deduced resonance widths for Θ_p=0.1. Where available, state energies from our ^{24}Mg(p,t)^{22}Mg measurement have been used.

interaction radius a=5.3 fm this results in a reduced width amplitude of γ=0.35 MeV$^{1/2}$. From

$$\Gamma = 2P\gamma^2(1 + \gamma^2(\frac{dS}{dE})_{|E_R}) \tag{1}$$

the width of each state can then be calculated. Resonances and widths of states in ^{21}Na are given in table 1. The maximum strengths of these resonances can be higher up to a factor of about 150 with $(\frac{dS}{dE})_{|E_R}$ slightly positive.

The initial target will be a polyethylen foil. For about 10^{18} atoms/cm^2 in such a foil the stopping in the c.m. system at the E_R=0.545 MeV resonance is about 20 keV. Integrating over this thickness and applying a simplified one channel cross section to the problem lets us estimate the effects of this resonance on an excitation function. The result for a laboratory angle of 30° (≈120° in c.m.) is shown in Figs. 3, 4, 5, and 6.

Obviously for a d-wave capture into this E_R=0.545 MeV resonance, the detectibility of this resonance becomes marginal. However, because the array provides the possibility to integrate over a wide angular range and select excitation functions around specific angles, we are confident to detect d-wave capture into the E_R=0.545 MeV resonance. As shown in Table 1, effects for the E_R=0.461 MeV resonance are about a factor five smaller. The detection of d-wave capture into this state may therefore be difficult, but both s- and p-capture with reasonable strengths will be detected. With a cross section of about 25 mb/sr and a 1° ring coverage, a 10^{18} cm^2 target and 10^8 s^{-1} beam, one expects then 0.09 events/s or 5 events/minute. For laboratory angles towards 90° this rate will quickly rise while for smaller laboratory angles the decline is relatively slow. Coverage of a large solid angle (10° to 70°) will then allow to obtain quickly a good statistical accuracy.

We will determine the beam charge deposited by measuring and integrating the beam current at the insulated TUDA scattering chamber. However, an absolute knowledge of the target thickness and the integrated charge is not necessary, because it can be shown

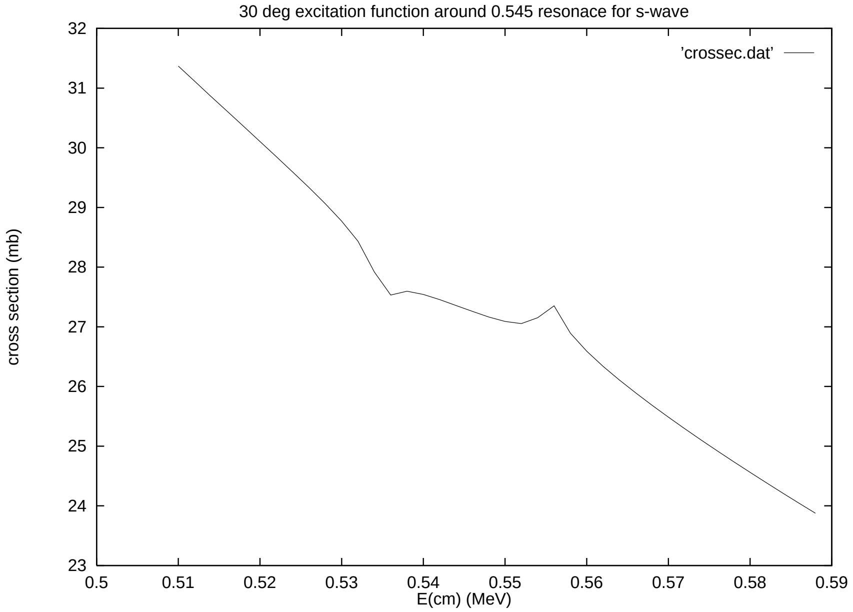


Fig. 3 Excitation function at a laboratory angle of 30° over the E_R=0.545 MeV resonance assuming s-wave capture and Θ_p=0.1 integrated over a target thickness of 20 keV in the cm system.

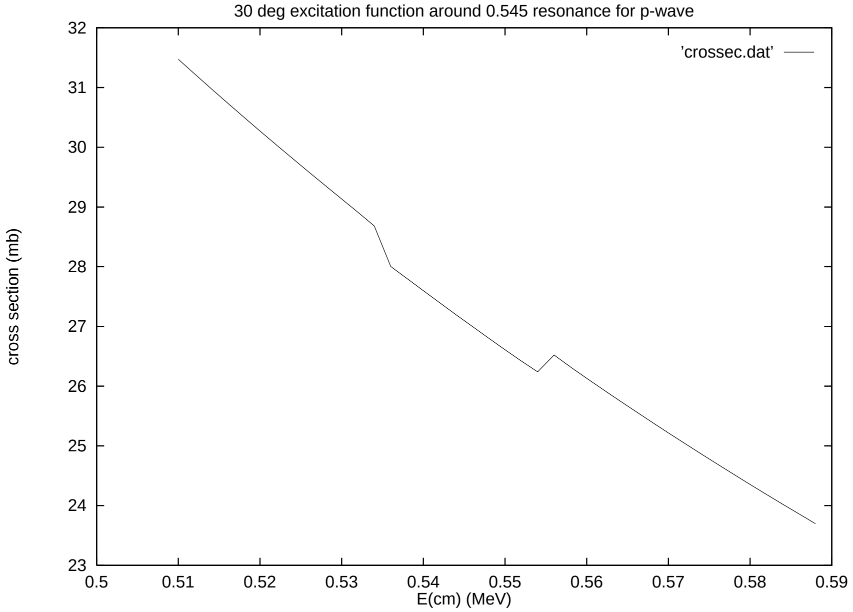


Fig. 4 Excitation function at a laboratory angle of 30° over the E_R=0.545 MeV resonance assuming p-wave capture and Θ_p=0.1 integrated over a target thickness of 20 keV in the cm system.

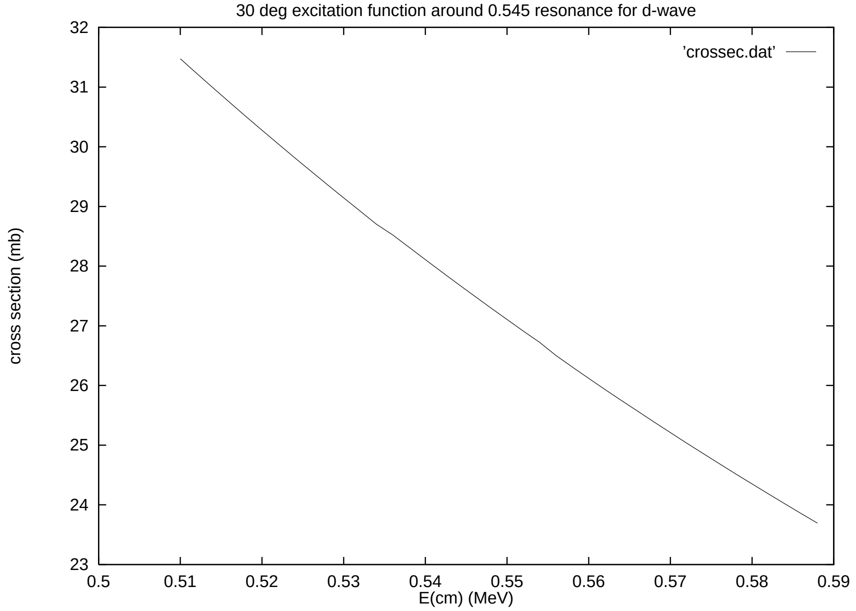


Fig. 5 Excitation function at a laboratory angle of 30° over the E_R=0.545 MeV resonance assuming d-wave capture and Θ_p=0.1 integrated over a target thickness of 20 keV in the cm system.

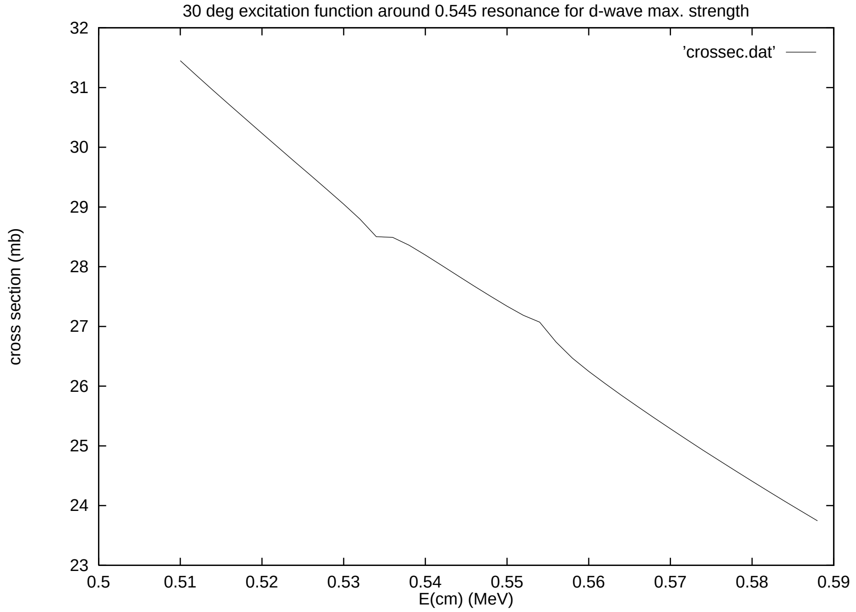


Fig. 6 Excitation function at a laboratory angle of 30° over the E_R=0.545 MeV resonance assuming d-wave capture and Θ_p=1.0 integrated over a target thickness of 20 keV in the cm system.

that the ratio of yields between different angles produces the same resonance information as absolute excitation functions.

For testing the predicted behaviour of the TUDA array we propose the use of the ^{23}Na(p,γ)^{24}Mg reaction in inverse kinematics. This reaction is characterized by a number of very well known broad resonances in the energy range between 0.2 and 1.0 MeV/u which have been observed in the elastic (p,p), the (p,γ), and the (p,α) channel. We propose to use these low energy resonances for testing the behaviour, the sensitivity and the efficiency of the TUDA array. The 1^+ resonance at 0.836 MeV (center of mass energy) has a width of 7.5 keV and can be easily identified in the elastic channel. The 2^+ resonance at 1.046 MeV (center of mass energy) has a total width of 5 keV and can be observed in the elastic channel, but should also be observable in the (p,α) channel. This would provide information about the sensitivity of the array since the ^{23}Na(p,α) resonance strength is very well known. Known low energy resonances can be used to investigate the limitations of the device towards narrow resonances. We therefore propose to search for the resonances at 0.567 MeV/u (Γ=0.64 keV) and at 0.325 MeV/u (Γ=0.7 keV). In addition we propose to look for the resonance at 0.240 MeV/u (Γ=1.75 keV) to test the low energy response of the facility. The ^{23}Na beam can be provided by the external ECR source while the ^{21}Na beam is being developed. It is expected that for stable beams TUDA will be rate limited by the data acquisition system. Therefore we do not expect to use currents far in excess of 10^8 s^{-1} for the same target thicknesses as used with radioactive beams. Therefore approximately the same counting rates as for ^{21}Na will be recorded.

3 Readiness

The installation of TUDA has been extensively discussed with the TRIUMF management. In summary, it is planned that the detector array including the chamber and electronics is machined, bought and assembled at the University of Edinburgh and shipped to TRIUMF in March to early summer 2000. At the same time an instrumentation cabin to shield of electronic noise and to provide stable temperature conditions will have been constructed by TRIUMF. It is envisaged that after two months the system is ready for tests with α-sources. Even with generous leeway for problems, TUDA will be operational and ready for stable and radioactive beam by September 2000.

4 Beam Time required

The results of the experiment and the need for beamtime will be critically dependent on the amount of radioactive beam currents which will be delivered to the target. We assume that currents in the order of 10^8 s^{-1} will be available from the begin of the experiment, still at least one order of magnitude less of what is required at DRAGON for the radiative capture reaction. If beams initially are significantly less, the experiment will be restricted to measure a coarse excitation function with a rather thick polyethylene target. Another critical parameter is the time needed for making energy changes on the ISAC DTL. Because we plan to measure excitation functions, many of those will be necessary. For sake of argument, we assume the average beam energy change time here to be 15 minutes. To cover an excitation function with a relatively thick target about 20 steps with 50 keV energy change in the centre of mass are necessary. Taking less than an hour to accomplish each step, a day of running time would be sufficient. Stepping with a thinner target in about 20 steps over known resonances should take another day. However, with such short runs, the actual need for running time will be probably "bug"-dominated, and we would therefore like to double the numbers of days to four. One day for setup with stable, and one day for setup with radioactive beam should be added. If radioactive beams intensities would be less, down to the 10^7 s^{-1} level run times would simply scale up while the "bug" rate will likely approximately stay constant. Below the level of 5×10^6 s^{-1} of beam we would likely forgo statistical and experimental accuracy. It should be pointed out that similar experiments have been performed down to beam levels of less than 10^4 s^{-1}. For the ^{23}Na beam experiment, we expect a short run some days which will be largely used to test and debug the system. We request therefore initially 3 shifts for testing our system with ^{23}Na+p. However, occassional hour long runs on ^{23}Na maybe requested in the ^{21}Na run to check out the system.

5 Data Analysis

The plans for a data acquisition system for TUDA are well advanced. The system will be based on VME coupled to CAMAC and is expected to handle event rates of up to 50 kHz. Events will be written both onto disk and tape (DLT) from a PC based system. For data analysis both systems in Edinburgh as well as here will be available. In particular, we are setting up a BEOWULF cluster (TRIBEC) and should manage to invoke up to 100 300-500 MHz CPU's in simultaneous data analysis if an NSERC grant for such a cluster is approved.

It has proven to be extremely computer intensive to fit actual elastic (and inelastic) scattering data of extended excitation functions of high statistical accuracy using multi-channel approaches and employing realistic experimental conditions requiring e.g. integration of steeply varying functions over the energy range of the target. At the moment we are gaining experience in parallel processing for similar problems ($^{12}C+\alpha$ scattering) using the MPI standard for message passing and should be able by the end of 1999 to master the computational effort necessary using TRIBEC.

References

1. N.Bateman et al., Proposal E824 to the TRIUMF EEC, July 1997.
2. P.M.Endt, Nucl. Phys., A521, 1 (1990)
3. H. Grawe, K. Holzer, K. Kändler, and A. A. Pilt, Nucl. Phys., A 237, 18 (1975)

Include publications in refereed journal over at least the previous 5 years.

1. E.G.Adelberger, S.A.Austin, J.N.Bahcall, A.B.Balantkin, G.Bertsch, G.Bognert, L.S.Brown, L.Buchmann, F.E.Cecil, A.E.Champagne, L. de Braeckeleer, C.A.Duba, S.E.Elliott, S.J. Freedman, M.Gai, C.Goldring, C.R.Gould, A.Cruzinov, W.C.Haxton, K.M. Hoeger, E.Henley, C.W.Johnson, M. Kamionskowski, R.W. Kavanaugh, S.E.Koonin, K.Kubodera, K.Langanke, T. Motobayashi, V, Pandharipande, P.Parker, R.G.H. Robertson, C.Rolfs, R.F. Sawyer, N.Shaviv, T.D.Shoppa, K.Snover, E.Swanson, R.E.Tribble, S. Turck-Chiene, and J.F. Wikerson, "Solar Fusion Rates", Rev. Mod. Phys., 70 (1998) 1265

2. J.Görres, J. Meißner, H.Schatz, E.Stech, P.Tischhauser, M.Wiescher, R.Harkewics, B.Sherrill, M.Steiner, D. Bazin, M.Hellström, D.J.Morrissey, R.N.Boys, L.Buchmann, D.H.Hartmann, J.D.Hinnefeld," Lifetime of ^{44}Ti as probe of supernova models", Phys. Rev Lett. 80 (1998) 2554

3. J.C.Chow, A.C.Morton, R.E.Azuma, N.Bateman, R.N.Boyd, L.Buchmann, J.M.D'Auria, T.Davinson, M.Dombsky, W.Galster, E.Gete, U.Giesen, C.Iliadis, K.P.Jackson, J.D.King, G.Roy, T.Shoppa, and A.Shotter, "Three-particle break-up of the isobaric analogue state in ^{17}F", Phys. Rev. C 57, (1998) R475

4. J.A.Behr, A.Gorelov, T.Swanson, O.Häusser, K.P.Jackson, M.Trinczek, U.Giesen. J.M.D'Auria, R.Hardy, T.Wilson, P.Choboter, F.Leblond, L.Buchmann, M.Dombsky, C.D.P. Levy, G.Roy, B.A.Brown, and J.Dilling, "Magneto-optic trapping of β-decaying ^{38m}K, ^{37}K from an on-line isotope separator", Phys. Rev. Lett. 79, (1997) 375

5. J.D'Auria, L.Buchmann, D.Hutcheon, P.Lipnik, D.Hunter, J.Rogers, R.Helmer, U.Giesen, A.Olin, P.Bricault, N.Bateman, "A facility for studying radiative capture reactions induced with radioactive beams at ISAC", Nucl. Inst. Meth. B, 126 (1997) 262

6. L.Buchmann, "New stellar reaction rate for ^{12}C(α,γ)^{16}O", Ap.J., 468 (1996) L127, Erratum: Ap.J., 479 (1997) L153

7. C.Iliadis, R.E.Azuma, L.Buchmann, J.Chow, J.M.D'Auria, M.Dombsky, U.Giesen, J.D.King, and A.C. Morton, "Beta-delayed particle decay of ^{36}K", Nucl. Phys. A 609 (1996) 237

8. L.Buchmann, R.E.Azuma, C.A.Barnes, K,Langanke, and J.Humblet, "An analysis of the total ^{12}C(α,γ)^{16}O cross section based on available angular distributions and other primary data", Phys. Rev. C, 54, (1996) 393

9. C.Iliadis, L.Buchmann, P.M.Endt, H.Herndl, and M.Wiescher, "New stellar reaction rates for ^{25}Mg(p,γ)^{26}Al and ^{25}Al(p,γ)^{26}Si", Phys.Rev. C, 53 (1996) 475

10. R.E.Azuma, L.Buchmann, F.C.Barker, C.A.Barnes, J.D'Auria, M.Dombsky, U.Giesen, K.P. Jackson, J.D.King, R.Korteling, P.McNeely, J.Powell, G.Roy, J.Vincent, T.R.Wang, S.S.M.Wong, and P.W.Wrean, "Constraints on the low-energy $E1$ cross section of ^{12}C(α,γ)^{16}O from the β-delayed α-spectrum of ^{16}N", Phys. Rev. C., 50 (1994) 1194 Erratum Phys. Rev. C., 56 (1997) 1655

11. M.Dombsky, L.Buchmann, J.M.D'Auria, U.Giesen, K.P.Jackson, J.D.King, E.Korkmaz, R.Korteling, P.McNeely, J.Powell, G.Roy, M.Trinczek, and J.Vincent, "β-delayed α-Decay of ^{17}N", Phys. Rev. C, 49 (1994) 1867

12. S.Kubono, C.C.Yun, R.N.Boyd, L.R.Buchmann, Y.Fuchi, M.Hosaka, N.Ikeda, C.L.Jiang, I.Katayama, H.Kawashima, H. Miyatake, T.Niizeki, T.Nomura, A.Odawara, M.Ohura, H.Ohnuma, H.Orihara, C.Rolfs, T. Shimoda, Y. Tajima, M.H.Tanaka, and H.Toyokawa, "High resolution study of ^{24}Mg(d,p)^{23}Mg for the Ne-E problem", Z.Phys. A 348 (1994) 59

13. L.Buchmann, R.E.Azuma, C.A.Barnes, J.D'Auria, M.Dombsky, U.Giesen, K.P. Jackson, J.D.King, R.Korteling, P.McNeely, J.Powell, G.Roy, M.Trinzcek, J.Vincent, S.S.M.Wong, and P.W.Wrean "A study of beta delayed alpha emission from ^{16}N" Nucl. Inst. Meth., B79 (1993) 330

14. L.Buchmann, R.E.Azuma, C.A.Barnes, A.Chen, J.Chen, J.D'Auria, M.Dombsky, U.Giesen, K.P. Jackson, J.D.King, R.Korteling, P.McNeely, J.Powell, G.Roy, M.Trinzcek, J.Vincent, S.S.M.Wong, and P.W.Wrean "The β-delayed α-spectrum of ^{16}N and the low-energy extrapolation of the ^{12}C(α,γ)^{16}O cross section", J. Phys. G Nucl. Part. Phys. 19 (1993) S115

15. L.Buchmann, R.E.Azuma, C.A.Barnes, J.D'Auria, M.Dombsky, U.Giesen, K.P. Jackson, J.D.King, R.Korteling, P.McNeely, J.Powell, G.Roy, J.Vincent, T.R.Wang, S.S.M.Wong, and P.W.Wrean, "β-delayed α-spectrum of ^{16}N and the ^{12}C(α,γ)^{16}O cross section at low energies", Phys. Rev. Let. 70,6 (1993) 726

16. J.M.D'Auria, L.Buchmann, M.Dombsky, P.McNeely, G.Roy, H.Sprenger, and J.Vincent, "Upgrade of the TRIUMF on-line separator, TISOL", Nucl. Inst. Meth., B70 (1992) 75

17. M.Dombsky, L.Buchmann, J.M.D'Auria, P.McNeely, G.Roy, H.Sprenger, and J.Vincent, "Targets and ion sources at the TISOL facility", Nucl. Inst. Meth., B70 (1992) 125

18. L.Buchmann, J.Vincent, H.Sprenger, J.D'Auria, M.Dombsky, P.McNeely, and G.Roy, "The ECR ion source at the TRIUMF isotope separator TISOL", Rev.Sci.Instrum., 63,4 (1992) 2387

19. C.D.P.Levy, L.Buchmann, K.Jayamanna, M.McDonald, R.Ruegg, P.W.Schmor and A.N.Zelenski, "A d.c. polarized H^{-} ion source based on optically pumped rubidium", Rev.Sci.Instrum., 63,4 (1992) 2625

20. L.Buchmann, J.Vincent, H.Sprenger, M.Dombsky, J.M.D'Auria, P.McNeely, and G.Roy, "The ECR ion source at the TRIUMF isotope separator, TISOL", Nucl. Inst. Meth. B62 (1992) 521

21. J.D.King, D.Frekers, R.Abegg, R.E.Azuma, L.Buchmann, C.Chan, T.E.Drake, R.Helmer, K.P.Jackson, L.Lee, C.A.Miller, E.Rost, R.Sawafta, R.Schuhbank, S.S.M.Wong, S.Yen, and X.Zhu, "Excitation of the 10.957 MeV 0^{-}; T=0 state in ^{16}O by 400 MeV Protons", Phys.Rev.C, 44, 3 (1991) 1077

22. L.Buchmann, K.Jayamanna, C.D.P.Levy, M.McDonald, R.Ruegg, P.W.Schmor, A.Belov, V.G.Polushkin, and A.N.Zelenski, "A DC optically pumped, polarized H^{-} source", Nucl. Inst. Meth. (1991), A306 (1991) 413

23. L.Buchmann, "A proton polarimeter for beam energies below 300 keV", Nucl. Instr. Meth. (1991), A301 (1991) 383

24. J.D'Auria and L. Buchmann, ”Radioactive beams facilities: A status report”, Nucl. Instr. Meth. B56/57 (1991) 516

25. M.Dombsky, J.M.D'Auria, L.Buchmann, H.Sprenger, J.Vincent, P.McNeely, and G.Roy, ”Target and ion source development at the TISOL facility at TRIUMF”, Nucl. Instr. Meth., A295 (1990) 291

26. J.M. D'Auria, M.Dombsky, L.Buchmann, and J.S. Vincent, ”Studies related to the production of an isotopically pure ^{22}Na radioactive target”, Nucl. Instr. Meth. A288 (1990) 354

27. P.McNeely, G.Roy, J.Soukup,J.M.D'Auria, L.Buchmann, M.McDonald, P.W.Schmor, H.Sprenger, and J.Vincent, ”The UoA/TRIUMF radioactive beam ECR ion source”, Rev.Sci.Instrum. 61,1 (1990) 273

28. J.M.D'Auria, M.Dombsky, L.Buchmann, J.D.Vincent, and J.D.King, ”The proposed ISAC facility at TRIUMF”, Nucl. Instr. Meth., B40/41 (1989) 418

29. M.Wiescher, J.Gőrres, S.Graff, L.Buchmann, F.-K. Thielemann, ”The hot pp-Chains in Low Metallicity Objects”, Ap. J. 343 (1989) 352

30. L.Lee, T.E.Drake, S.S.M.Wong, D.Frekers, R.E.Azuma, L.Buchmann, A.Galindo-Uribari, J.D.King, R.Schubank, R.Abegg, R.Helmer, K.P.Jackson, C.A.Miller, and S.Yen,”Intermediate-energy proton scattering to the ground and negative parity states of ^{40}Ca , ^{90}Zr and ^{208}Pb”, Nucl. Phys. A492 (1989) 607

31. L.Lee, T.E.Drake, S.S.M.Wong, D.Frekers, R.E.Azuma, L.Buchmann, A. Galindo-Uribarri, J.D. King, R.Schubank, R.Abegg, R. Helmer, K.P. Jackson, C.A.Miller,and S.Yen,” Inelastic proton scattering to the positive-parity states in ^{90}Zr at 400 MeV”, J.Phys. G, 15 (1989) L91

32. P.McNeely, G.Roy, J.Soukup, J.M.D'Auria, L.Buchmann, M.McDonald, P.W.Schmor, and H.Sprenger, ”An ECR ion source for radioactive beams at TRIUMF”, J.d.Phys., 50 (1989) Cl 807

33. L.Buchmann, J.M.D'Auria, and P.McCorquodale, ”Stellar reaction rates of alpha capture on light ($N \neq Z$) Nuclei and their astrophysical implications”, Ap. J.,324 (1988) 953

34. L.Lee, T.E.Drake, S.S.M. Wong, D.Frekers, R.E.Azuma, L.Buchmann, A. Galindo-Uribari, J.D.King, R.Schubank, R.Abegg, R.Helmer, K.P.Jackson, C.A. Miller, S.Yen, and H.V. von Geramb, ”Intermediate energy proton scattering from ^{40}Ca , ^{90}Zr and ^{208}Pb”, Phys. Lett. B, 205 2,3, (1988) 219

35. L.Buchmann, J.M.D'Auria, J.D.King, G.Mackenzie, H.Schneider, R.B.Moore, and C.Rolfs, ”An Isol/postaccelerator facility for nuclear astrophysics at TRIUMF”, Nucl. Instr. Meth., B26 (1987) 151

36. L.Buchmann, T.Mattman, J.M.D'Auria, E.Devita, H.Schneider, A.Otter, H.Sprenger, and P.W.Schmor, ”A conceptual design of an ECR source for an Isol facility”, Nucl. Instr. Meth., B26 (1987) 253

37. J.E.Crawford, J.K.P.Lee, R.B.Moore, H.Dautet, F.Buchinger, K.Oxorn, L.Nikkinen, J.M.D'Auria, L.Buchmann, J.Vincent, and J.King, "A proposed radioactive beam facility at TRIUMF", Nucl. Instr. Meth. B26 (1987) 128

38. K.Oxorn, J.E.Crawford, H.Dautet, J.K.P.Lee, R.B.Moore, L.Nikkiinen, L.Buchmann, J.M.D'Auria, R.Kokke, A.J.Otter, H.Sprenger, and J.Vincent, "The installation of a prototype on-line isotope separator at TRIUMF (TISOL)", Nucl. Instr. Meth., B26 (1987) 143

39. U.Schrőder, A.Redder, C.Rolfs, R.E.Azuma, L.Buchmann, C.Campbell, J.D. King, and T.R. Donoghue, "Astrophysical S Factor of $^3H(\alpha,\gamma)^7Li$ ", Phys. Lett. B, 192 1,2 (1987) 55

40. H.P.Trautvetter, H.W.Becker, U.Heinemann, L.Buchmann, C.Rolfs, F.Ka̋ppeler, M.Baumann, H.Freiesleben, H.J.Lutke-Stetzkamp, P.Geltenbort, and F.Gonnenwein, "Destruction of ^{26}Al in explosive nucleosynthesis", Z.Phys.A, 323 (1986) 1

41. C.A.Miller, A.Scott, R.Abegg, R.Helmer, K.P.Jackson, M.Whiten, S.Yen, L.Lee, T.E.Drake, D.Frekers, S.S.M.Wong, R.E.Azuma, L.Buchmann, A. Galindo-Uribari, J.D.King, R.Schubank, R.Dymarz, H.V. von Geramb, and C.J.Horowitz, "Large angle elastic scattering of 200 MeV protons from ^{208}Pb", Phys. Lett., 169B, 2,3 (1986) 166

42. L.Lee, T.E.Drake, L.Buchmann, A.Galindo-Uribarri, R.Schubank, R.J. Sobie, D.R.Gill, B.K.Jennings, N. de Takacsy, "Evidence for the suppression of multiple scattering in^{12}C(π,π') at low energies", Phys. Lett. B, 174, 2 (1986) 147

43. L.Buchmann, J.M.D'Auria, G. Mackenzie, H.Schneider, R.B.Moore, " Development of a radioactive beams (RB) accelerator using ISOL as a source", IEEE, Nucl. Sc. 32,5 (1985) 3330

44. L.Buchmann, M.Hilgemeier, A.Krauss, A.Redder, C.Rolfs, H.P. Trautvetter, and T.R. Donoghue, "The abundance of ^{26}Al in the MgAl cycle", Nucl. Phys., A415 (1984) 93

45. L.Buchmann, H.Baumeister, and C.Rolfs, "The fabrication of ^{26}Al targets", Nucl. Instr. Meth., B4 (1984) 132

46. P.Schmalbrock, H.W.Becker, L.Buchmann, J.Gőrres, C.Rolfs, H.P.Trautvetter, and W.S.Rodney, "Search for γ-ray transitions within the ^{5}Li Groundstate", Z. Phys. A., 310 (1983), 243

47. J.Gőrres, H.W.Becker, L.Buchmann, C.Rolfs, P.Schmalbrock, H.P.Trautvetter,, A.Vlieks, J.W.Hammer, T.R.Donoghue, “Proton-induced direct capture on ^{21}Ne and ^{22}Ne”, Nucl. Phys., A408 (1983), 279

48. P.Schmalbrock, H.W.Becker, L.Buchmann, J.Gőrres, K.U.Kettner, W.E.Kieser, H.Kra̋winkel, C.Rolfs, and H.P.Trautvetter, “Stellar reaction rate of ^{20}Ne(α,γ)^{24}Mg”, Nucl. Phys., A398 (1983) 279

49. K.U.Kettner, H.W.Becker, L.Buchmann, J.Gőrres, H.Kra̋winkel, C.Rolfs, P.Schmalbrock, H.P.Trautvetter, and A.Vlieks, "The ^{4}He(^{12}C,γ)^{16}O reaction at stellar energies", Z. Phys. A, 308 (1982) 73

50. H.W.Becker, L.Buchmann, J.Gőrres, K.U.Kettner, H.Krǟwinkel, C.Rolfs, P.Schmalbrock, H.P.Trautvetter, and A.Vlieks, ”A supersonic jet gas target for γ spectroscopy measurements”, Nucl. Inst. Meth., 198 (1982) 277

51. H.Krǟwinkel, H.W.Becker, L.Buchmann, J.Gőrres, K.U.Kettner, W.E. Kieser,R.Santo, P.Schmalbrock, H.P.Trautvetter, A.Vlieks, C.Rolfs, J.W. Hammer, R.E.Azuma, W.S.Rodney,” The ^{3}He(α ,γ)^{7}Be reaction and the solar neutrino problem”, Z. Phys. A., 304 (1982) 307

52. L.Buchmann, H.W.Becker, K.U.Kettner, W.E.Kieser, P.Schmalbrock, and C.Rolfs, ”Stellar reaction rate of ^{26}Mg(p,γ)^{27}Al ”, Z. Phys. A., 296 (1980) 273

53. K.Elix, H.W.Becker, L.Buchmann, J.Gőrres, K.U.Kettner, M.Wiescher, and C.Rolfs, “Search for low-energy resonances in ^{25}Mg(p,γ) ^{26}Al”, Z. Phys. A, 293 (1979) 261