EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN-INTC-2003-026
INTC-P-178
28 August 2003

Proposal to the INTC Committee

Inelastic branch of the stellar reaction ^{14}O(α,p)^{17}F

P.J.Woods[1], D.G.Jenkins[2], M.Aliotta[1], F.Ames[3], C.Barton[2], U.Bergmann[3], J.Cederkäll[3], T.Davinson[1], J.Eberth[4], S.Emhofer[3], L.Fraile[3], S.Franchoo[3], R.Glover[2], D.Habs[5], M.Hass[6], O.Kester[5], Z.Liu[1], P.Mayet[7], A.St.J.Murphy[1], B.S.Nara Singh[6], O.Niedermaier[8], T.Nilsson[3], P.Reiter[4], H.Scheit[8], T.Sieber[3], P.van Duppen[7], N.Warr[4], D.Weisshaar[4], F.Wenander[3],
REX-ISOLDE and Miniball collaboration

1) University of Edinburgh, UK, 2) University of York, UK, 3) CERN, Switzerland, 4) IKP Köln, Germany, 5) LMU München, Germany, 6) Weizmann Institute, Israel, 7) KU Leuven, Belgium, 8) MPI-K Heidelberg, Germany

Spokesperson: P.J.Woods
Contact person: J.Cederkäll

Abstract

We propose to use the upgraded REX-ISOLDE beam energy to study the astrophysically important ^{14}O(α,p)^{17}F reaction in time reverse kinematics. In particular, we will use the highly efficient miniball + CD detection system to measure the previously undetermined inelastic proton branch of the 1^- state at 6.15 MeV in ^{18}Ne. This state dominates the reaction rate under X-ray burster conditions.

1 Introduction

The nucleus ^{14}O ($t_{1/2}$=71 s) forms an important waiting point at the proton drip line in X-ray burster scenarios [1]. The ignition of this reaction at temperatures ~0.4 GK produces a rapid increase in power and can lead to breakout from the hot CNO cycles into the rp process with the production of medium mass proton-rich nuclei. Excepting the ^{15}O(α,γ)^{19}Ne reaction, it is arguably the most important reaction to be determined for X-ray burster scenarios. Studies of the levels in the compound system ^{18}Ne [2] have shown that the reaction rate in the important temperature regime ~

0.5-1 GK is dominated by reactions on a single 1^- resonance at an excitation energy of 6.15 MeV lying 1.04 MeV above the ^{14}O + α threshold energy of 5.11 MeV.

Ideally one would study this reaction directly, but post-accelerated radioactive beams of ^{14}O of sufficient intensity have yet to be achieved for this low energy regime (see for example [3]). An alternative approach adopted by Harss et al. at Argonne [4] has been to study the time reverse reaction ^{17}F(p,α)^{14}O in inverse kinematics with ^{17}F beam intensities $\sim 10^5$-10^6 pps. Since the proton threshold energy in ^{18}Ne corresponds to a lower excitation energy (3.922 MeV) than the α threshold energy, the time reverse reaction requires relatively higher beam energies to feed the alpha unbound states. Harss et al. [4] identified levels above an excitation energy of 7 MeV in ^{18}Ne and determined their resonance strengths. Later work by Gomez del Campo et al. at Oak Ridge reported the observation of a simultaneous 2p decay channel from the 1^- state at 6.15 MeV in ^{18}Ne using ^{17}F + p inverse resonance scattering with a ^{17}F beam current $\sim 10^5$pps [5]. The total width of the state was measured to be 50(5) keV compared with a 2p decay branch $\sim$3 orders of magnitude lower [5]. In a subsequent work by Harss et al. [6] the results from [5] were combined with a measurement of the ^{17}F(p,α)^{14}O excitation function from [4] to provide an approximate estimate of the alpha partial width ($\sim$3 eV) and resonance strength ($\sim$ 1 eV) for the 1^- state at 6.15 MeV [6].

A major defect of using the time reverse approach is that it does not take account of inelastic excitations in the exit channel of the astrophysical reaction. The inclusion of inelastic channels increases the reaction rate, and can do so significantly. In the present case it means that the proton exit channel leading to the 1st, and only, particle bound, excited state at 495 keV in ^{17}F is excluded from calculations. Harss et al. [6] were able to identify some inelastic components from inverse proton scattering, but were only able to separate these from the elastic components 'in favourable cases', and in particular no inelastic proton branch was reported for the important 1^- resonance at 6.15 MeV, this being the only completely undetermined parameter for this state. The main purpose of the present proposal is to identify and determine the unknown inelastic proton branch from the 1^- astrophysical resonance in ^{18}Ne to the first excited state in ^{17}F.

2 Experiment

The 1^- state at 6.15 MeV in ^{18}Ne corresponds to a centre of mass energy E_{cm} = 2.22 MeV for the ^{17}F + p system [5]. The recent increase in the beam energy for the REX-ISOLDE accelerator system means it is now possible to feed this resonance using inverse scattering of ^{17}F ions on a $(CH_2)_n$ target. We anticipate ^{17}F currents from REX-ISOLDE $\sim 3\times 10^4$pps . Unlike earlier studies described above we plan to take advantage of the state-of-the-art mini-ball + CD system to measure proton+gamma coincidences in order to identify the proton branch to the first excited state in ^{17}F. A gamma detection efficiency of $\sim$30 % is expected for the 495 keV γ-ray which will suffer a relatively small degree of Doppler broadening in comparison with Coulex studies. The protons will be detected and identified using the annular geometry CD system developed by the Edinburgh Group as part of the REX-ISOLDE collaboration. In this instance a thin ΔE CD detector system ($\sim$50μm) will be placed in front of a 500μm thick E detector system covering a laboratory angular range from 10–40 degrees, corresponding to proton energies $\sim$7–4 MeV. Elastically (resonant + Rutherford) scattered protons will dominate the rate in the proton energy region corresponding to the broad 1^- resonance [5]. The inelastic branch and width will be obtained from a comparison of the yields for the inelastic and elastic branches - the total width of the 1^- state has already been determined from [5] although a new measurement can be achieved here.

We would plan to run over a centre of mass energy regime from $\sim$2.1-2.3 MeV covering the 1^- resonance, and corresponding to a ^{17}F beam energy of 41 MeV (2.4 MeV/u) with a $(CH_2)_n$ target thickness $\sim$300 μgcm^{-2}. For a beam current of 3×10^4 pps, this would imply the detection $\sim$$10^3$ protons per day from the 1^- resonance assuming a detection efficiency $\sim$10% and taking the total width from [5]. This in turn would imply a proton-gamma photopeak rate $\sim$ 300b_p per day, where b_p is the unknown inelastic branch to the 495 keV state in ^{17}F. This should be a very clean signature. The main background would be expected to come from elastically scattered protons in coincidence with random γ-ray background. However, by using a relatively thin $(CH_2)_n$ target, elastically scattered protons from the target will have energies clearly above those of inelastically scattered protons at a given angle. Positron-gamma coincidences will be filtered out by particle identification using the CD system. A small amount of background may be expected from evaporation protons from the sub-barrier fusion with ^{12}C in the target, but these rates will be low [5], and the protons in general will have a broad distribution of energies. In principle, there could be a small component of background due to non-resonant proton scattering of ^{17}F to the first excited state at 495 keV. However, this mechanism would have a continuum of proton energies and should be straightforwardly distinguished from protons produced from the resonance mechanism, whose energy distribution will reflect the resonance energy distribution in the target.

We would request a total of 5 days running, which would include time for online setting up of electronics and detectors. This should permit the observation of an inelastic branch in excess of 1%.

As a by product of the main experiment, a few proton–proton coincidence events corresponding to 2p decay from the 1^- state in ^{18}Ne may also be observable. However, a higher projected ^{17}F beam intensity would be required to achieve comparable statistics with [5]. That said, the CD detector system provides much higher angular resolution than the system used in [5] which means with comparable statistics the present experiment could provide a much more sensitive probe of the presently undetermined decay mechanism (^{2}He emission or 3-body/democratic decay). A measurement of the even weaker α–branch from the 1^- state is probably outside the present sensitivity range of the experiment and would need higher beam intensities with a dedicated set-up including recoil detection.

As a further byproduct of this study it will be possible to study inelastic scattering of ^{17}F on ^{12}C to the $1/2^+$ proton halo state in ^{17}F to determine the B(E2) connecting the $5/2^+$ ground-state. The lifetime of the transition de-exciting this state has been measured in earlier work.

If this initial experiment was successful we would next plan to extend the technique to the ^{21}Na + p system in order to study inelastic channels populated in the ^{18}Ne(α,p)^{21}Na astrophysical reaction. This reaction may provide an alternate route to breakout into the rp process in X-ray bursters.[7].

References

[1] M Wiescher et al., Phil. Trans. R. Soc. London A346, 2105 (1998).

[2] KI Hahn et al., Phys. Rev. C54, 1999 (1996).

[3] J Powell et al., Nucl. Inst. Meth. B204, 440 (2003).

[4] B Harss et al., Phys. Rev. Lett. 82, 3964 (1999).

[5] J Gomez del Campo, Phys. Rev. Lett. 86, 43 (2001).

[6] B Harss et al., Phys. Rev. C65, 035803 (2002).

[7] D Groombridge et al., Phys. Rev. C66, 055802 (2002).