ELSEVIER
SCIENCE

BaF array for γ-tagged studies with radioactive nuclear beams

H. Amro*[a], F.D. Becchetti[a], Hao Jiang[a], M.Ojaruega[a], J.J. Kolata[b], B. Skorodumov[b], G. Peaslee[c], P.D Young[c], D. Denby[c], J.D. Hinnefeld[d]

[a]*Department of Physics, University of Michigan, Ann Arbor, Michigan 48109-1120, USA.*

[b]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556-5670, USA*

[c]*Department of Physics and Engineering, Hope College, Holland, Michigan 49422-9000, USA.*

[d]*Department of Physics, Indiana University-SB, South Bend, Indiana 46634-7111, USA.*

Elsevier use only: Received date here; revised date here; accepted date here

Abstract

The use of a high-efficiency BaF spectrometer for in-beam γ-tagged γ-ray spectroscopy of low-energy radioactive nuclear beams (RNBs) is examined in this study. Our results demonstrate that although BaF detectors have poor energy resolution, they still can (with proper tagging to eliminate background) be a highly efficient tool for in-beam γ-ray spectroscopy of RNBs.

Keywords: gamma-tagging; radioactive nuclear beams;BaF scintillators

1. Introduction

Gamma-ray spectroscopy with radioactive nuclear beams (RNBs) is a powerful tool to study exotic nuclei not reachable with stable beams. The challenges using this experimental tool can be difficult to overcome. One of the main challenges is the low intensities of RNBs as compared to those of stable beams, *i.e.* usually several orders of magnitude lower. To even make the matter even worse, RNBs are always accompanied by secondary products that reach the target and produce a tremendous amount of background γ-rays which obscure the γ-rays of interest. Such background mainly is due to the large flux of fast neutrons produced in the primary reaction used in RNB production. The large efficiency of BaF spectrometers can compensate to some useful extent for the low intensities of RNBs. However, these spectrometers are known to have poor energy resolution in comparison to high-purity Ge detectors. The poor resolution of BaF spectrometers when used in RNB reactions

* Corresponding author: hamro@nd.edu

is a great disadvantage due to the overwhelming number of γ-rays present in such experiments. It is therefore imperative to develop a technique to select the γ-rays of interest from the multitude of γ-rays detected by the BaF spectrometer during the experiment.

We examined the use of γ-ray tagging techniques in overcoming such problem at the U.of Michigan-U. of Notre Dame *TwinSol* RNB facility located at the University of Notre Dame [1,2,3].

2. Experimental details

A ^{3}He gas cell at 1.3 atm pressure with thin entrance Ti window (~3 μ) and a thin (~9 μ) ^{9}Be exit window was bombarded with a 30.5 MeV ^{7}Li stable beam. A ^{8}Li RNB was produced via the ^{9}Be(^{7}Li,^{8}Li)^{8}Be reaction. The primary beam was monitored by a suppressed in-line Faraday cup, which also served as the beam stop and zero-degree fast-neutron block. The *TwinSol* facility consists of two superconducting solenoid magnets and was used to focus the ^{8}Li beam at the secondary target position.

The use of intense primary beams results in the production of a large background protons, neutrons, γ-rays, etc. Without proper shielding, γ-ray spectroscopy is impossible. In that case, *TwinSol* must run in "*parallel mode*" *i.e.* used as a long, high-Bρ, single-magnet for bending the ions of the most magnetically-rigid beams [1]. The secondary beam in this case is focused semi-parallel to the beam axis by the first magnet and the final focusing on the secondary target is done by the second magnet. In this mode, a substantial radiation and neutrons shielding can be placed between the second solenoid and the final focal point. In addition, a heavymet bar could be placed along the beam axis for neutron absorption. This setup is illustrated in fig.1.

To measure the production of the secondary beam and to identify all particles focused at the secondary target, this beam is imaged using a position sensitive silicon detector (PSD) placed at the target position. This detector is ~200 micron thick with an active area of 485 mm^{2}. A 19 micron SiSB detector was placed in front of the PSD to form a ΔE-E telescope for particle identification.

In this setup, about 10^{6}/s of ^{8}Li are produced at the secondary target for ~500 electrical *nA* of primary ^{7}Li beam. The ^{8}Li beam has an energy spread of ~0.5 MeV FWHM and angular divergence of ~6^{o} FWHM. A two-dimensional spectrum is shown in Fig. 2 illustrating the various ions produced and focused on the secondary target.

The chamber housing the secondary target is located at ~7.5 m downstream of the RNB production target behind a wall of borated de-ionized water for further neutron shielding.

An array of four BaF detectors surrounding the reaction chamber is used for γ-ray detection. Each detector is a single-crystal 85% relative-efficiency scintillator coupled to a fast PMT.

A self supporting ~1 mg/cm^{2} ^{nat}Pb target was used as a secondary target. Two ΔE-E SiSB detector telescopes were mounted at 90^{o} and 60^{o} with respect to incident beam to be used for particle detection and identification. A picture of this setup is presented in Fig. 3.

Time of flight (TOF) information are recorded by a TAC which starts by a SiSB signal and stopped by a BaF signal. The TOF is used later to reject random coincidences events between SISB and BaF detectors.

3. ^{8}Li+^{208}Pb reactions near the Coulomb barrier

Several reaction channels are observed for the ^{8}Li+^{208}Pb interactions near the Coulomb barrier (*i.e.* 28 MeV) in this experiment: elastic scattering of ^{8}Li RNB off ^{208}Pb, inelastic scattering of the ^{8}Li; and; one-neutron transfer to ^{208}Pb yielding ^{209}Pb. The latter two reaction mechanisms are followed by γ-ray emission. These γ-rays are collected by the BaF spectrometer surrounding the reaction chamber. The raw γ-ray spectra collected by the 4 BaF detectors are shown in Fig. 4.

Clearly, the γ-rays of interest are completely obscured by the huge background radiation. The γ-ray tagging technique is then employed to select γ-rays corresponds to different reaction channels present in this data.
Fig. 5 shows the total γ-ray spectrum from all four BaF detectors gated by TOF and, most importantly, by ^{8}Li (inelastic channel) and ^{7}Li (one-neutron channel) reaction products collected by the SiSB telescopes. Known γ-rays in ^{8}Li, ^{7}Li and ^{209}Pb (see Fig. 6) are clearly visible in this spectrum. These results shows, for the first time, that the strong ^{7}Li groups observed in this experiment mainly are from one-neutron transfer channel.

4. Summary

γ–ray spectroscopy using RNBs is especially difficult. The challenges are mainly due to the low intensities of RNBs and the large yield of background radiation present as a byproduct of the RNB production. We investigated the use of BaF γ-ray spectrometer which is highly efficient with good timing properties to compensate for the low intensity of RNB. To select the γ-rays of interest from the large background radiation, we tagged the γ-rays with ions detected in the SiSB telescopes. Our results demonstrate that BaF scintillators can be efficiently used in γ–ray spectroscopy using low-energy RNBs.

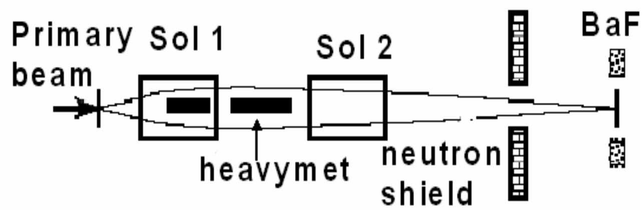

Fig. 1. Schematics of the *TwinSol* facility and the ^{8}Li beam trajectories. The two magnets are run in parallel mode [1] which allows for the use of a heavymet bar for fast neutron shielding.

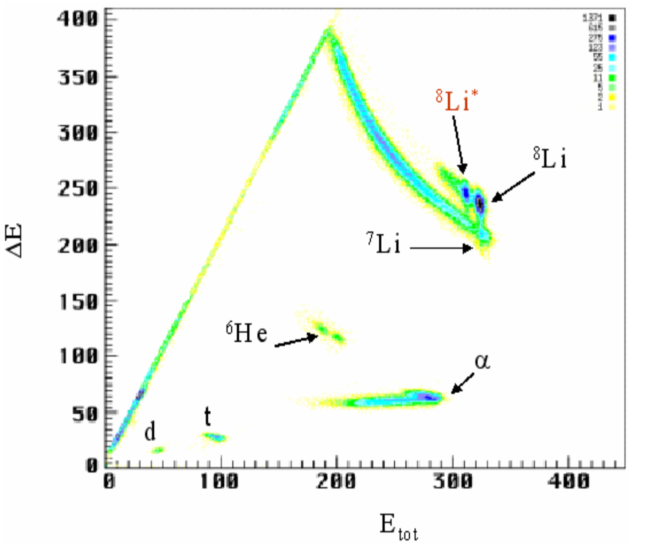

Fig. 2. A two-dimensional spectrum in the ΔE-E SiSB telescope showing the various ions produced and focused at the secondary target position.

Fig. 3 The BaF array used in this experiment surrounding the scattering chamber housing the secondary ^{208}Pb target and the SiSB telescopes. This setup is located behind the neutron shielding wall.

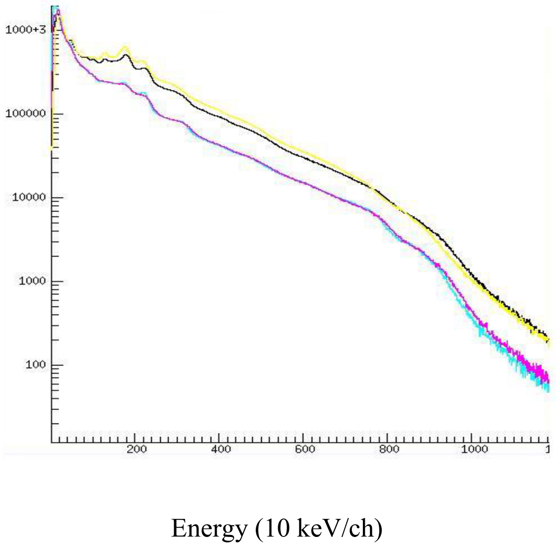

Fig. 4. γ-rays detected in the four BaF detectors This raw spectrum clearly illustrates the large background radiations present in the data.

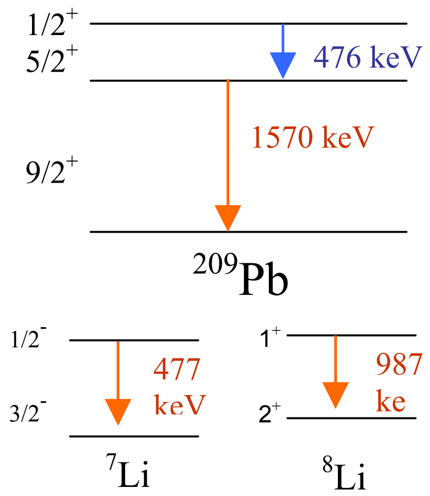

Fig. 6. Schematic illustrating the various reaction channels observed in this experiment: elastic and inelastic scattering of ^{8}Li off ^{208}Pb; and the one-neutron transfer leading to ^{209}Pb.

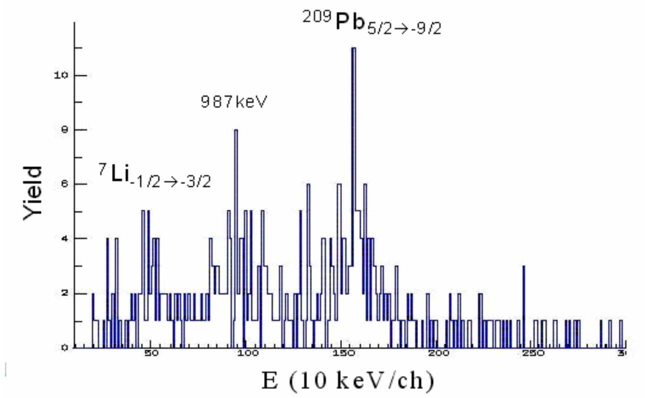

Fig. 5. A γ–ray spectrum measured in the BaF spectrometer gated by ^{8}Li and ^{7}Li ions detected in the ΔE-E telescopes and by TOF. γ-rays from various reaction channels are labeled (see Figure 6 for details). The difference observed between this spectrum and that shown in Figure 4 clearly illustrate the power of the tagging technique used in this experiment.

References

[1] M.Y. Lee, F.D. Becchetti, T.W. O'Donnell, D.A. Roberts, J.A. Zimmerman, V. Guimar#aes, J.J. Kolata, D. Peterson, P. Santi, P.A. DeYoung, G.F. Peaslee, J.D. Hinnefield, Nucl. Instr. and Meth. **A** 422 (1999) 536.
[2] http://www.physics.lsa.umich.edu/twinsol.
[3] "The TwinSol Low-energy Radioactive Nuclear Beam Apparatus: Status and Recent Results," F.D. Becchetti, M.Y. Lee, T.W. O'Donnell, D.A. Roberts, J.J. Kolata, L.O. Lamm, G. Rogachev, V. Guimares, P.A. DeYoung, S. Vincent, Nuclear Instrum. Methods A505 (2003) 377-380

Acknowledgements

This work was supported under NSF grants PHY-0354828 (UMICH), PHY-0457120(UND), and PHY-0354920 (Hope college).