DEVELOPMENT OF NOVEL NEUTRON AND GAMMA-RAY SCINTILLATORS: Cs_2LiYCl_6 and $CeBr_3$

BY

NATHAN W. D'OLYMPIA
B.S. UNIVERSITY OF MASSACHUSETTS LOWELL (2010)

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE
DEPARTMENT OF PHYSICS AND APPLIED PHYSICS
UNIVERSITY OF MASSACHUSETTS LOWELL

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Thesis Supervisor: Partha Chowdhury

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Abstract

With an increasing need to improve existing detector technology for both basic and applied nuclear science, an effort has been made to significantly further the development of two promising inorganic scintillators, Cs_2LiYCl_6 (CLYC) and $CeBr_3$. CLYC is a dual neutron/γ scintillator with excellent pulse-shape discrimination and good energy resolution. Direct fast neutron spectroscopy is possible due to the ^{35}Cl(n,p) reaction, whereas thermal neutron detection is accomplished using the ^{6}Li(n,α) reaction. A study of the fast neutron response in CLYC was performed at the UMass Lowell Van de Graaff using mono-energetic neutron beams between 0.8 to 2.6 MeV. Thermal neutron measurements were carried out using a moderated PuBe source and thermal beams from the UMass Research Reactor neutron radiography port. Simulations of the fast/thermal neutron response and efficiency were performed with the Monte Carlo code MCNPX (v2.7.0). Experiments with $CeBr_3$, a fast high light output γ-ray detector, focused on its excellent timing resolution ($\leq$250 ps). A pair of $CeBr_3$ detectors were used for direct measurements of nanosecond and sub-nanosecond isomers in ^{152}Sm and ^{177}Hf using the delayed coincidence technique. The position resolution of a positron emitting source placed between detectors was evaluated to assess the potential use of $CeBr_3$ as a time-of-flight positron emission tomography (TOF PET) detector. Additional characterizations were performed for both CLYC and $CeBr_3$, including energy resolution, timing resolution, efficiency, and pulse shape analysis.

Acknowledgement

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Chapter 1

Introduction

1.1 Inorganic Scintillators

As the frontiers of nuclear physics are pushed further towards exotic neutron-rich nuclei, and nuclear science becomes an increasing invaluable tool in a diverse range of applications, the need to advance the capabilities of detector technology becomes paramount. The past decade has seen a rapid increase in the development of radiation detectors for nuclear physics, medical physics, nonproliferation, nuclear energy research, and high energy physics. Amongst the various detector types being developed, inorganic scintillators have been ubiquitous throughout nuclear science since Rutherford used ZnS powder to detect α-particle backscattering from gold. While scintillators have now been in use for over a century, significant improvement over traditional detectors that have been in use since the 1950's is still being made.

The most common application of inorganic scintillators is γ-ray spectroscopy, with a more recent interest in neutron detection. For decades the standard has been thallium activated NaI. However, interest in finding better crystal compounds and activators has lead to the discovery of several scintillators that have been shown to be superior to NaI:Tl in regards to fundamental characteristics such as energy resolution, timing, and efficiency.

$CeBr_3$ is a recent fast unactivated scintillator which improves and all three aforementioned traits. For the past several decades cerium has become an increasingly popular activator for inorganic scintillators because of its fast decay time and reasonable light yield [1]. Because of this, there was interest in scintillators incorporating Ce as one of the primary constituents. $CeBr_3$ may naturally be compared to $LaBr_3$:Ce, another fast high-resolution γ-ray detector which has been under extensive study. $CeBr_3$ shares many of the same detection characteristics but is slowly attracting more attention for its low intrinsic activity compared to $LaBr_3$:Ce.

For crystals that incorporate a neutron sensitive isotope, a detector which is capable of measuring both neutrons and γ-rays can be made. One of the most recently popular and promising of these types is Cs_2LiYCl_6 (CLYC). CLYC has the unique properties of having good energy and timing resolution, while also being sensitive to both thermal and fast neutrons. Its versatile use as a dual neutron/γ detector is facilitated by its ability to clearly discriminate between neutron and γ-ray events based on pulse shapes. Together, CLYC and $CeBr_3$ represent two of the most interesting new inorganic scintillators whose combined applications span nearly all of nuclear science.

1.2 Scintillation Mechanisms

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