Energy Response of LaBr3

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Abstract: In recent years, important developments in scintillator technology have been made in the Lanthanum Halogen LaBr3 (Ce) crystal, which has high-energy separation, very good timing-properties and a stopping-power that can be used as a detector at room temperature. The international PARIS project will be created as a prototype of this detector system, which will be used in SPIRAL2 as a stand-alone or in collaboration with the EXOGAM or AGATA detector array. A fusion evaporation reaction is used to produce exotic nuclei and is then transferred at a very high angular momentum to compound nuclei. Due to the accompanying high rotation, the exotic shape starts changing into vibrational and rotational collective phenomena which hitherto have together become difficult to detect and fully understand. In order to perform this type of research, in addition to conventional known gamma-ray detectors, high-efficiency gamma-ray detectors that can effectively identify gamma rays are also required as calorimeters. LaBr3 is planned to use such means. Results of ongoing analysis for energy and the time response of LaBr3 will be presented.

1. Introduction

Producing and understanding the structure of exotic nuclei have become increasingly important in fundamental nuclear physics research nowadays. In order to produce this kind of exotic nuclei as well as understand what has been happening inside the nuclei, the use of both radioactive ion beams and high intensity neutron-rich beams is required. In experiments conducted using this type of beam, the reaction mechanism and nuclear structure of nuclei together their reaction products have become rather a problem in detecting. A fusion-evaporation reaction is used to produce exotic nuclei and is then transferred at a very high angular momentum to compound nuclei. Due to the accompanying high rotation, the exotic shape starts changing into vibrational and rotational collective phenomena, with the giant dipole resonance (GDR), have together become hard to detect and fully understand [1-2].

In order to perform this type of research, in addition to conventional known gamma-ray detectors, high-efficiency gamma-ray detectors that can effectively identify gamma rays are also required as calorimeters. With a view to achieving this aim in SPIRAL2, which is supported by the European Union F7P, the PARIS project was created so as to develop a prototype of this kind of calorimeter [3].

The PARIS project, designed only a few years ago with the active participation of Turkey, involves 16 countries and was created by 42 prestigious institutes. In recent years, developments in scintillator technology have been made in the LaBr3 (Ce) crystal, which has high-energy separation together with very good timing-properties and stopping-power that can be used as a detector at room temperature. The international PARIS project will be created as a prototype of the detector system, which in turn will be used in SPIRAL2 as stand-alone or in collaboration with the EXOGAM or AGATA detector array. This is the prototype detector needed to enhance the various universities and research laboratories in different countries which have specific individual tasks to undertake.
The principal aim is to increase the international dimension of activities assumed by the current researcher and that of subsequent new researchers. Furthermore, by using such an innovative technological product as the LaBr₃(Ce), new knowledge will be gained and consequently increase our country's strength and international competitiveness in the world of science and technology. The design of the international PARIS project will utilize either a cubic or a spherical geometry detector array. For this, three major projects are being investigated using different combinations of LaBr₃(Ce) and other scintillators, such as the CsI(Tl), BaF or NaI detectors. In both geometrical sets, the inner shell is going to consist of the LaBr₃(Ce), and the outer shell will comprise CsI(Tl), BaF or NaI materials. In the first design, the inner and outer shell materials will use separate each photo-multiplier (PMT); in the second one, the inner shell will use the avalanche photo diode (APD) and the "phoswich" type PMT combined with the outer shell; and, in the third design, the inner and outer shells will be together without any space directly combined, and both will use a single PMT as planned.

Our research group from Nigde University has been awarded a research grant from The Scientific and Technological Research Council of Turkey to participate in this international project, and now we are able to buy the essential crystals and electronics to carry out some experimental work as well as undertake simulations in Nigde University. Within this proposed project, we plan to study "LaBr₃(Ce) Scintillator detector either with a CsI(Tl) or NaI detector combined with a common photo-multiplier (PMT). In this way the performance of the detectors, together with the efficiency, energy and time-responses of the detectors would be determined.

Up-to-date different geometry and design studies have been carried out and, within the studies below, development and applications were performed:

1- Linearity, energy and time-discrimination tests.
2- Energy and time-responses of different combination, and design crystals and scintillator for different radioactive sources.
3- Real experimental performance of different combinations and design crystals and scintillator.
4- GEANT4 and ROOT codes for data acquisition, and spectral data analyses respectively.

2. Simulations and Results
In this presentation, we are going to present different results obtained both from simulations and actual measurements which have been carried out and investigated by different researchers from different countries. Before presenting the energy and time-response of a single crystal or an array for different geometry, a brief comparison will be presented in Fig 1a and Fig 1b. In Fig 1a, AGATA A180 geometry is based on tiling a sphere with 180 hexagons and 12 pentagons in which Ge material was replaced by LaBr₃. In Fig 1b, 200 LaBr₃ crystals with a size of 2"x2"x4" were used to create cubic geometry. Full absorptions of gamma-rays efficiency for cubic and AGATA A180 geometry are compared in Fig 2 [4].

There is a new geometry consisting of 200 LaBr₃ cubic crystals forming shell which covers almost 4pi angle. For this geometry, basic simulations with crystals of two sizes 2"x2"x2" and 4"x2"x2" are required. For these two crystal sizes, the individual efficiency of absorption and energy deposition for discreet gamma and for GDR-type emission were carried out. This new geometry was constructed, based on an AutoCad by John Strachan from Daresbury Laboratory, UK., and shows the full array with an implemented beam line. In Fig 3, we can see the geometries constructed from 200 LaBr₃ crystals using sizes 2"x2"x2" (left) and 4"x2"x2" (right) [5]. Having this type of geometry enables us to cover almost the whole 4pi angle and also permits us to use the entrance for the beam pipe.
Fig 1a: AGATA A180 geometry. The geometry is based on tiling asphere with 180 hexagons and 12 pentagons [4].

Fig 1b: Cubic geometry constructed with 200 LaBr3 crystals with a size of 2”x2”x4” [4].

Fig 2. Full absorption of gamma-ray efficiency for cubic and AGATA A180 geometry [4].

There has also been another upgrade for the geometry, as shown in Fig 4. This consists of adding 200 CsI crystals sized 6”x2”x2”. This new upgraded geometry using LaBr3 with CsI gives us better parameters when measured against previous geometry. This comparison between different sizes of LaBr3 and the combination with CsI is shown Fig 5, clearly demonstrating an absorption coefficient contingent on the geometry and energy of gamma-rays.

Fig 3. Visualization of geometry proposed by J. Strachan [5].

Fig 4. Another upgrade geometry proposed by J. Strachan [5].
There has been other work on geometries carried out, for instance, by G. Anil Kumar et al., which tried different scintillators and geometry in order to see their efficiency, energy resolution and time-response [6]. According to this test, the NaI crystal provided better energy resolution with improved efficiency than BGO and BaF2. But NaI has a large neutron-absorption cross-section, comprising a slow detector whereas BaF2 has much faster timing; but the energy resolution of BaF2 is far poorer than NaI. However, the recently developed LaBr3 scintillator seems to satisfy most of the requirements for an ideal spectroscopic detector. Despite the fact that the energy resolution of these crystals is significantly better than that for NaI, they do have very fast timing-properties. The PARIS array is expected to serve a dual purpose both as a sum-spin spectrometer and also a calorimeter for high energy gamma rays [6]. For this purpose, an array should cover as much of the solid angle as possible with best possible response for gamma-rays over a wide range of energy.

Absorption

![Absorption graph](image)

Fig 5. Absorption coefficient depending on geometry and energy of gamma-ray [4].

G. Anil Kumar studied simulation and considered an array of 32 tapering conical detectors for both pentagonal and hexagonal cross sections. After being arranged in close-packed geometry, the array covers the complete 4πi solid angle with an inner diameter of 10 cm. Fig 6 shows the drawings for both pentagonal and hexagonal detectors [6]. Fig 7 shows the 32 detectors the two halves having 16 detectors each.

Specifically for the PARIS array, another suggestion was proposed for the array and detectors geometry by Adam Maj [7]. There have been two configurations for the array, namely one spherical, the other cubic. The first option is better for angular distribution, the second is, however, more efficient and offers variable geometry. In this report, the size of LaBr3 and CsI crystals are 2”x2”x2” cubic and also 2”x2”x4” respectively. The total array is tiled around in order to have inner radii of between 15 cm (~50 detectors) and 25 cm (~200 detectors). For this juncture scenario, it would be advisable to know what size and shape of LaBr3 and CsI can be obtained from the manufacturer. Since the crystals are growing in cylindrical form, it is economic to obtain hexagonal instead of square ones. For this purpose, a circular cross-section with tapering, for instance truncated conical geometry with not so much compact packing can be considered [8]. Possible geometry is suggested in Reference [8]. Fig.8 and Fig.9 show a possible tapering of the LaBr3 and CsI junction with different sizes of CsI.
Table 1 below shows the calculation results for efficiencies and the response of an individual detector.

| Energy (MeV) | LaBr3 Conical Hexagon | LaBr3 Conical Pentagon |
|--------------|------------------------|------------------------|
|              | Absolute efficiency(%) | Absolute efficiency(%) |
| 0.662        | 3.21                   | 2.20                   |
| 1.173        | 2.93                   | 1.55                   |
| 1.132        | 2.89                   | 1.45                   |

Table 2 below shows the calculation results for efficiencies and the response of the array consisting of 32 detectors.

| Energy (MeV) | Absolute efficiency(%) | Photopeak efficiency(%) |
|--------------|-------------------------|-------------------------|
| 0.662        | 90.00                   | 71.00                   |
| 1.173        | 82.60                   | 55.63                   |
| 1.132        | 81.00                   | 52.75                   |
| 5            | 68.42                   | 32.63                   |
| 10           | 71.25                   | 25.64                   |
| 15           | 72.70                   | 18.38                   |
| 20           | 75.03                   | 11.37                   |
| 30           | 78.31                   | 4.41                    |
| 40           | 79.73                   | 1.56                    |
| 50           | 81.56                   | 0.55                    |

Fig 8. The conical tapering option for LaBr3 and CsI [8].

Fig 9. The conical tapering option for LaBr3 and CsI, tapering extended [8].
In order to have a greater thickness of the inner shell for better line shape 3” LaBr3 is used in Fig 9. After showing all these possible tapering options, Suresh Kumar suggested that a radial-placed tapered detector of a hexagonal or circular cross-section would have a high efficiency for the PARIS array and provide better reconstruction of energy and the fold of the events. Especially in terms of the higher thickness of LaBr3 crystal, this suggestion would not prove particularly expensive [8].

The figures below, Fig 10. And Fig 11. show the performance of the LaBr3 and BaF2 combination for both cubic and spherical geometry [9].

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