Experimental report

06/11/2024

Proposal: **CRG-3168**

Council: 4/2024

Title: Determination of neutron detection efficiency for an ionic scintillator

Research area: Physics

This proposal is a new proposal

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Samples: Imidazolium

Instrument	Requested days	Allocated days	From	To
SAM	2	2	01/07/2024	03/07/2024

Abstract:

The abstract is in the scientific case pdf file.

Experimental report CRG 3168

Title: Determination of neutron detection efficiency for an ionic scintillator

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Abstract

Luminescent organic salts open the way to new materials that combine excellent luminescence performance with the properties of salts (no vapor pressure, non-flammable, high chemical stability, etc.). We have synthesized and shaped centimeter-sized single crystals that detect and discriminate gamma rays and neutrons, over a wide energy range from cold neutrons to fast neutrons (CNRS/UdS, WO2023001818 (A1)). These detection properties are due to the combination of an organic cation containing hydrogen atoms with an anion containing ^{10}B. This scintillator could be an interesting alternative to the ^{3}He gas detectors used in Large Research Facilities.

Principle

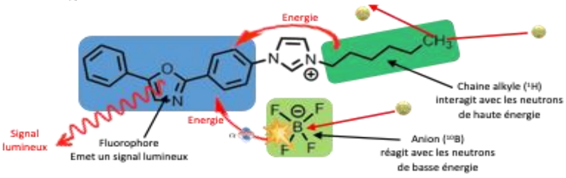

Figure 1: Lumoxa molecule, slow and fast neutron detection mechanism.

The Lumoxa salt is made up of three distinct functional parts: an imidazolium core, a molecular Lego that can be easily functionalised. Each of these three parts plays its own role: the alkyl chain interacts with high-energy neutrons (0.1-15 MeV) via its hydrogen atoms by inelastic scattering, the BF_4 counterion reacts with low-energy neutrons (<10 keV) via the ^{10}B isotopes in a nuclear reaction, releasing a $^{7}Li^{+}$ ion and an alpha particle (energy 1.47 MeV). The neighbouring fluorophores capture the energy and release it in the form of a 20 ns pulse of 400 nm blue light (Fig.1, left). It is therefore possible to discriminate between the different types of radiation by analysing the slow component of the decay of luminescence in our material, which differs according to the type of radiation (Fig.1, right).

Main text

An initial measurement campaign in July 2024 demonstrated excellent neutron absorption properties of Lumoxa: transmission measurements through pure monocrystals of the material showed a transmission of less than 0.2% of the beam for a 4 mm thick crystal, and only 5% transmission at 5 Å for a 1 mm thick crystal (Fig.2).

λ	E (meV)	Transmission
3.6 Å	6.3	0.12 %
5 Å	3.3	0.02 %
11.3 Å	0.64	0.01 %
20 Å	0.20	0.00 %

Λ	Transmission
5 Å	5.19 %

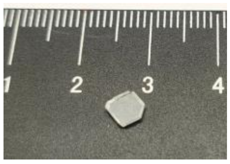

Figure 2: Transmissions for two Lumoxa crystals as a function of wavelength. Data for the 4 mm thick crystal on the left and the 1 mm thick crystal on the right.

By replacing the LiZnS scintillator in the Barotron device (CEA-CNRS patent, DI 86688-01), we were able to show qualitatively that our Lumoxa crystals efficiently absorb and convert neutrons into blue photons that can be detected by the optical sensor integrated into the Barotron device (Fig.3 left). Now the proof of concept is done, numerous experiments are needed using a Pulse-Shape Discrimination device to obtain absolute detection yields of those crystals at different wavelength and crystals thickness.

Lumoxa have also been dispersed in resin to form scintillator plates. We compared the efficiency of the Lumoxa plates (Fig. 3 right) with that of the conventional LiZnS scintillator. The best sample showed currently a detection efficiency around 153x less efficient than LiZnS. However, this comparison remains qualitative insofar as some of the light emitted by the Lumoxa is scattered in the material due to its large thickness (>1 mm).

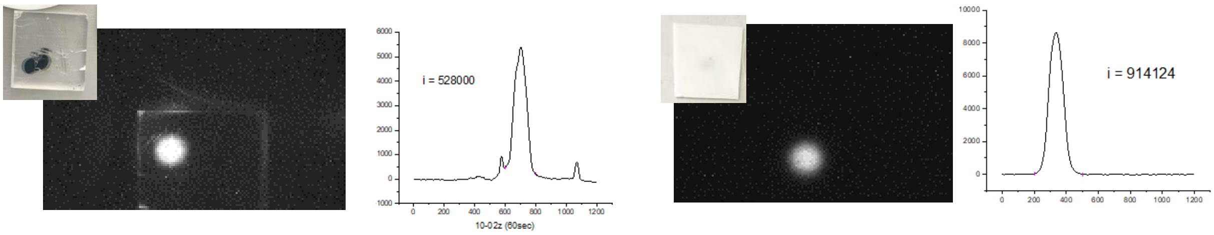

Figure 3: Left: 2D image and profile of the detection intensity per single crystal by neutron absorption (exposure 60s, thickness 4mm, approximately 99.98% according to the transmission at 5Å, optical sensor of the Barotron device). Note that a large proportion of the light propagates in the crystal, illuminating its edges and the neighbor samples.
Right: 2D image and profile produced by a resin incorporating Lumoxa (Absorption rate: around 80% at 5Å for an uncontrolled thickness between 1.1 and 1.8 mm, exposure time 60s, optical sensor on the Barotron device).

This first series of experiments has established the proof of concept of these new scintillators. We aim now at improving the photonic efficiency by controlling several parameters as the plate thickness, enrichment, concentration and dispersion at different neutron wavelengths, using the new spectrometer SAM. Excellent detection efficiencies coupled with a solid detector (and transparent in the case of crystals) open up numerous prospects for the French manufacture of new detectors that are more compact, more efficient, less dangerous and less costly.
We warmly thank Nicolas Martin for his interest and assistance during the experiment.