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Neutron Detection with a Cryogenic Spectrometer

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INTRODUCTION

Cryogenic calorimeters are used for x-ray detection because of their exquisite energy resolution[1] and have found application in x-ray astronomy, and the search for dark matter.[3] These devices operate by detecting the heat pulse produced by ionization in an absorber cooled to temperatures below 1 K. Such temperatures are needed to lower the absorber's heat capacity to the point that the deposition of even a few eV results in a measurable temperature excursion.

Typical absorbers for dark matter measurements are massive Si or Ge crystals, and, with Ge, have achieved a resolution of 650 eV at 10 keV[4]. Chow, *et al.,*[5] report the measurement of the 60 keV emission from ^{241}Am with 230 eV resolution using a superconducting tin absorber. Cunningham, *et al*.,[6], also using a superconducting tin absorber, have recently reported a four-fold improvement over Chow.

With such results being reported from the x- and gamma ray world it is natural to examine the possibilities for cryogenic neutron spectroscopy. Such a detector would operate by detecting the heat pulses caused by neutron capture and scattering. To date, ^{6}LiF has been the absorber of choice because relatively large crystals can be grown, and it is an insulating material with low heat capacity. Silver[2] reports the fabrication of a ^{6}LiF spectrometer operating at 328 mK and achieving a resolution of 39 keV. De Marcillac[7] reports the fabrication of a spectrometer operating at 80 mK and achieving 16 keV resolution when bombarded with 5 MeV alpha particles.

In this paper, we report preliminary results with a TiB_2 absorber exposed to thermal neutrons. In contrast to lithium, whose chemistry selects for LiF as the absorber, boron offers a rich chemistry from which to select materials with high boron content. We will discuss the considerations governing the choice of absorber material as well as the basic considerations needed to understand a cryogenic spectrometer. The capture and scattering reactions in boron and lithium were modeled with MCNP. The modeling results and methods of analysis applicable to lithium- and boron-based spectrometers will be given.

CRYOGENIC SPECTROMETER

The cryogenic spectrometer consists of an absorber mounted on a Mo-Cu transition edge sensor (TES), in turn mounted on a silicon nitride membrane in contact with a cold bath. The cold bath is realized as a two-stage adiabatic demagnetization refrigerator (ADR). The ADR used two paramagnetic salts in contact with thermally isolated nested cold fingers to hold the absorber near 100 mK.[8]

The TES consists of alternating layers of Mo and Cu, the number and thicknesses of which determine the temperature at which it switches from the superconducting state to normal-conduction. However, the transition occurs over a temperature range measured in mK, and is nearly linear over a portion of that range. Consequently, for heat pulses in an appropriately sized absorber, the change in resistance is proportional to the deposited energy.

A weak thermal link separates the TES and membrane, and determines the rate at which heat

is drawn from the absorber into the cold bath. The time constant for the instrument is approximately 80 ms and is a determined by the thermal conductivity of the thermal links and the heat capacity of the absorber.

SELECTION OF ABSORBER

The energy, $Q + E_n$, involved in neutron absorption is measured in MeV. To achieve a temperature change less than 1 mK, it is necessary for the absorber to have a heat capacity of about 1 nJ/K.

In the present design, the silicon nitride membrane limits the mass of the absorber to a few milligrams. At 120 mK (the operating temperature of the TES), the heat capacities of milligram pieces of LiF, and insulating, semi- and superconducting boron compounds are too small. Consequently, normal-conducting boron compounds were evaluated. It was found that TiB_2 has reasonably high boron content and measurement of the heat capacity confirmed its suitability.

MEASUREMENT OF NEUTRONS

The TES with the TiB_2 specimen mounted on it were mounted in the spectrometer and exposed to neutrons from a 10^7 n/s ^{252}Cf source placed within a U-shaped moderator/safety shield constructed from bricks of pressed boric acid powder. The spectrometer sat at the open end of the "U." Although boron in the bricks limited the thermal flux available to the detector, the count rate was approximately 0.75/s.

RESULTS

Pulses were accumulated over the course of 3 hours and sorted according to amplitude. Peaks, approximately in the ratio of 16:1, corresponding to the ground state and first excited state of ^{7}Li were observed in the spectrum at 2.31 and 2.8 MeV deposited energy. Fitting the initial unfiltered data determined the FWHM to be 15 keV. In subsequent filtered data the resolution improved to 11.3 keV at 2.31 MeV and 5.3 keV at 2.8 MeV. Work to further improve the filtering and resolution is continuing.

It should be noted that the resolution of this type of spectrometer is a function of the operating temperature[5], rather than the deposition energy. Consequently, the same several keV resolution is expected to be observed with MeV neutrons as well. The high resolution offered by this instrument opens the door to neutron spectroscopy without recourse to time of flight or unfolding methods. Looking to the future, it would be expected that the spectrometer would be able to distinguish between different fission sources, and between fission and radioactive sources. This may even be possible even in the presence of moderator or shielding.

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