Nuclear Instruments and Methods in Physics Research A 599 (2009) 248–250

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Multi-wire proportional chamber for ultra-cold neutron detection

C.L. Morris [a,*], T.J. Bowles [a], J. Gonzales [a], R. Hill [a], G. Hogan [a], M. Makela [a], R. Mortenson [a], J. Ramsey [a], A. Saunders [a], S.J. Seestrom [a], W.E. Sondheim [a], W. Teasdale [a], H.O. Back [b], R.W. Pattie Jr. [b], A.T. Holley [b], A.R. Young [b], L.J. Broussard [c], K.P. Hickerson [d], J. Liu [d], M.P. Mendenhall [d], B. Plaster [d], R.R. Mammei [e], M. Pitt [e], R.B. Vogelaar [e], R. Rios [f], J. Martin [g]

[a] *Physics Division, Group P-25, Mail Stop H846, Los Alamos National Laboratory, Los Alamos, NM 87544, USA*
[b] *North Carolina State University, Raleigh, NC 27695, USA*
[c] *Duke University, Durham, NC 27708, USA*
[d] *California Institute of Technology, Pasadena, CA 91125, USA*
[e] *Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA*
[f] *Idaho State University, Pocatello, ID 83209, USA*
[g] *University of Winnipeg, Winnipeg, Man. R3B 2E9, Canada*

ARTICLE INFO

Article history:
Received 27 August 2008
Received in revised form
10 September 2008
Accepted 18 November 2008
Available online 3 December 2008

Keywords:
Ultra-cold neutrons
Multi-wire proportional detector

ABSTRACT

In this paper we describe the principles that have guided our design and the experience we have gained building multi-wire proportional chambers detectors for the ultra-cold neutron (UCN) source at the Los Alamos Neutron Science Center (LANSCE). Simple robust detectors with 50 cm^2 of active area have been designed. These have been used both in ion chamber and proportional mode for the detection of UCN.

Published by Elsevier B.V.

1. Introduction

The interaction of neutrons with materials is typically determined by the material's nuclear potential. At sufficiently low energies, the neutron wavelength is long enough that the material surface acts as a potential barrier, given by the Fermi potential, V_F [1]:

$$V_F = \frac{2\pi\hbar^2}{m} Na.$$

where m is the neutron mass, N is the number density of the material, and a is the coherent nuclear scattering length. Therefore, these neutrons can be trapped in material bottles, as long as the scattering length is positive. Neutrons with kinetic energies below the V_F of the trapping material are referred to as ultra-cold neutrons (UCNs). ^{58}Ni is often used as a trapping surface due to its large V_F, 342 meV.

The ability to transport, store, and manipulate the spins of UCN has led to a broad experimental program that has been reviewed by Ignatovitch [2], and by Golub et al. [3]. Recently, new technologies have been developed for producing UCN that promise sources with higher intensities and fluxes than have been obtained from reactor-driven sources [4–7]. In this paper we describe UCN detectors that have been developed and that are in use at the UCN source at the Los Alamos Neutron Science Center (LANSCE).

2. Design

Little is published on the design and construction of proportional chambers for detecting UCN. The idea of using gas-filled detectors for thermal neutrons goes back to Fermi [8]. We have developed robust and simple multi-wire proportional detectors to monitor the UCN flux from the Los Alamos UCN source. The first detectors used $^{10}BF_3$ as the fill gas in a proportional detector. Thermal neutrons are absorbed by the reaction ^{10}B(n,t)7Li, releasing 2.79 MeV of kinetic energy in the charged particles that ionize the gas. The resulting electrons are collected and amplified in the high electric field around a small diameter anode wire that is placed at several kV of potential relative to the tube that contains the gas.

^{3}He provides a safer alternative to $^{10}BF_3$ through the reaction ^{3}He(n,p)^{3}H, with a Q-value of 0.764 MeV. ^{3}He gas does not have

*Corresponding author. Tel.: +1 505 667 5652; fax: +1 505 665 7920.
E-mail address: cmorris@lanl.gov (C.L. Morris).

0168-9002/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.nima.2008.11.099

the stopping power of BF_3, so detectors are often filled with an additional stopping gas that produces higher ionization energy loss and stopping power for the energetic ions produced in the neutron capture reaction. After the reaction, the triton has an energy of 191 keV and the proton has 573 keV. Fluorocarbon stopping gases are ideal because they provide high stopping power and small neutron absorption cross-sections. At 1 bar of pressure and temperature 20°C, the sum of the ranges in CF_4 of the two charged particles is 0.48 cm compared to 1.60 cm in argon and 6.0 cm in ^{3}He. In order to obtain the best signal-to-noise, the detector must have active detector volume dimensions that are largely compared to the ranges in order to reduce the fraction of events, where energy is lost in the detector walls rather than in the active gas volume.

The thermal neutron cross-section for the reaction 3He(n,p)t is σ=5.333 kb. At low energies the lifetime ($\tau=1/(\rho\sigma v)$, where ρ is the ^{3}He number density), is independent of neutron velocity because the cross-section varies like $1/v$ with neutron velocity, v. For gas mixtures where the neutron absorption is dominated by capture on ^{3}He the lifetime is $\tau=(3.55\times10^{-5}/P)$ s, where P is the ^{3}He pressure in bars. Neutrons with v=5 m/s have a mean free path of $l=v\tau$ of 9 mm with 20 mbar of ^{3}He pressure. The detector must be several mean free paths thick in order to optimize the detector efficiency and the mean free path needs to be larger than the charged particle range to minimize the wall effects.

We have designed a detector, shown in Fig. 1, which is approximately planar. The detector incorporates two cathodes held at ground, the entrance window and a copper circuit board. At the approximate center is an anode plane which is held at high voltage. The active volume is determined by the distance between the two cathode planes, 5 cm. Grid planes, spaced 2.5 mm from the anode, ensure uniform fields in the anode region even though the entrance window is held by a flange, and is bowed by the gas pressure.

The anode planes were constructed on a FR-80 frame with 20 μm gold-plated tungsten wires spaced by 2 mm and wound at 50 g of tension. The wires were epoxied to the plane and soldered to the copper tabs. The ends of the wire plane were terminated with 75 μm beryllium–copper guard wires wound at 100 g m of tension. The grid planes were of similar construction with 2 mm spaced 75 μm gold-plated copper-clad aluminum wire also at 50 g m of tension.

For detecting UCN, one must use low absorption materials for the entrance windows. We used aluminum alloy windows (6061 T6) which are strong, robust and provide relatively low losses. The window in the detector presents both a potential barrier and introduces UCN losses due to absorption and scattering. With the detector mounted 1 m below the beam line (using gravity to accelerate the UCN), we have measured the transmission of UCN falling through a 0.025-cm-thick window to be 50%. Monte Carlo modeling suggests that about half of the losses are absorption in the material and half are due reflections off of the non-specular surface.

Recently, we have measured the strength and transmission of UCN through zirconium metal foils. Zirconium, 50 μm, is capable of robustly supporting >4 bar of pressure with about 80% transmission. We hope to try this as a detector foil soon.

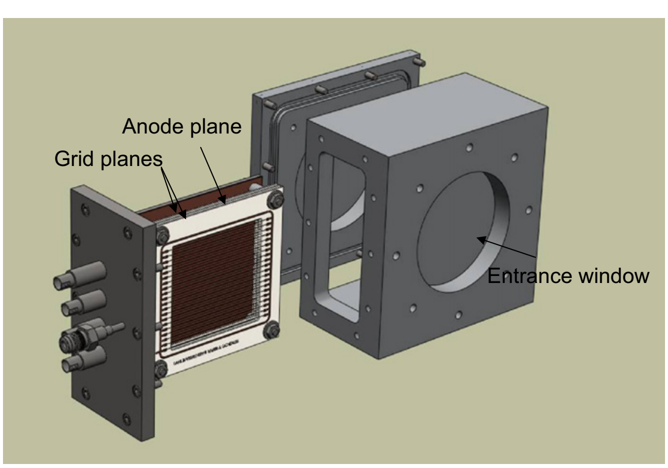

Fig. 1. Schematic view of the detector assembly.

3. Results

We present a typical spectrum obtained for UCN from the LANSCE source with one of these detectors mounted after a fall of 1 m into the detector in Fig. 2. The detector was operated with 2600 V on the anode and 390 V on the grid planes. The pulses were amplified with an Ortec 142PC pre-amplifier and shaping amplifier and read into a peak-sensing ADC. The detector gain at this voltage is ~6. The cosmic and gamma ray backgrounds are low in this set up so that the edges due to wall effects are apparent in the histogram. The typical resolution was 3% for the five detectors that were tested.

In an earlier work, we used detectors of a similar construction in ion chamber mode. In the laboratory this mode of running provides similar resolution and high gain stability, but was much more susceptible to both electronic and microphonic noise. Maintaining good resolution in detectors with gas gain required

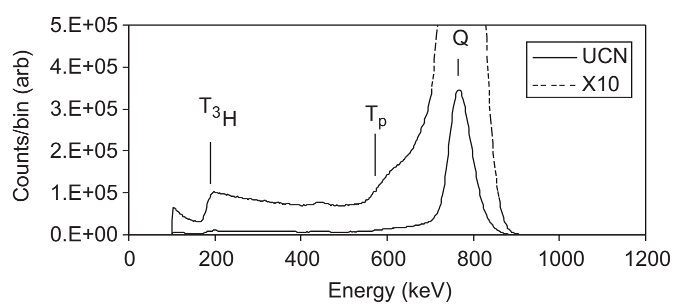

Fig. 2. Pulse height spectrum obtained with a UCN beam. The detector is operating with V_A=2600 and V_C=390 V. The spectra shows a peak at the ^{3}He(n,p)^{3}H Q-value as well as edges at the energies of both reaction products due to wall effects, indicated by arrows.

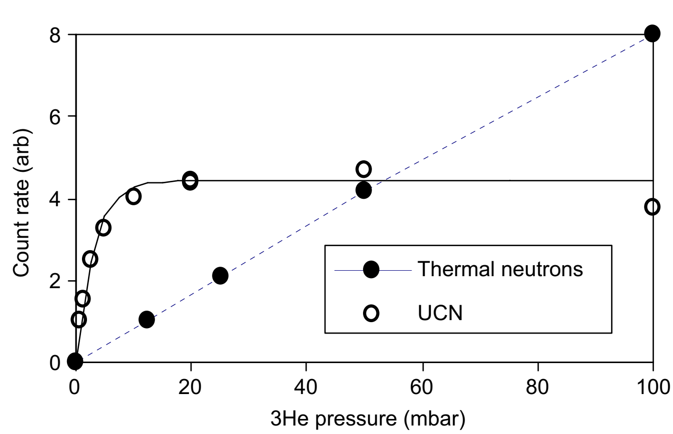

Fig. 3. Relative neutron efficiency for a moderated 252Cf source (dashed line) and for UCN (solid line) as a function of ^{3}He partial pressure. The solid curve through the UCN data is a calculation of the efficiency.

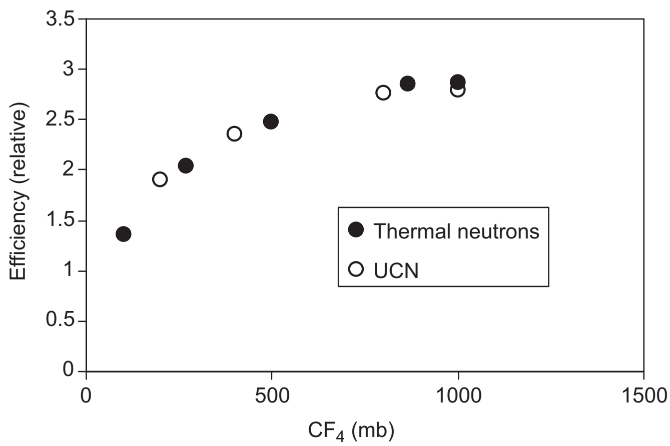

Fig. 4. Relative efficiency of the full energy peak as a function of stopping gas pressure. The voltage was adjusted at each pressure to give a constant gain.

tighter dimensional tolerances (we achieved ~100 μm precision in wire spacing and plane spacing), but reduced the susceptibility of the electronic and the microphonic noise to negligible levels.

The relative detector efficiency as a function of ^{3}He fill pressure, for both thermal and ultra-cold neutrons is shown in Fig. 3. For thermal neutrons the efficiency is linear with ^{3}He pressure, but for UCN the efficiency saturates at relatively low ^{3}He pressure as expected. The solid curve through the UCN data is a calculation of the UCN efficiency assuming that the mean velocity of neutrons in the detector is 4.4 m/s due to the 1 m drop to the detector and the lifetime given by the ^{3}He absorption cross-section.

In Fig. 4 we plot the relative full energy efficiency for thermal neutrons as a function of stopping gas pressure. For both thermal neutrons and UCN, the efficiency is observed to plateau at about 1 bar of CF_4. Therefore, we have chosen a conservative combination of 0.025 cm 6061 T6 aluminum window with 1 bar of stopping gas pressure.

4. Conclusions

A simple and robust design for a multi-wire ^{3}He ultra-cold neutron detector has been presented. The performance has been measured for both thermal and ultra-cold neutrons. The pulse-height resolution was measured to be 3%. The full energy efficiency is 80% for neutrons that make it through the entrance window. Transmission through the window for neutrons that are dropped 1 m into the detector was measured to be 50%. We hope to significantly improve this transmission by using zirconium windows in future.

Acknowledgments

This work has been supported in part by the US Department of Energy, by the National Science Foundation and by Los Alamos National Laboratory internal funding (LDRD)

References

[1] E. Fermi, W.N. Zinn, Phys. Rev. 70 (1946) 103.
[2] V.K. Ignatovitch, Physics of Ultra-Cold Neutrons, Clarendon, Oxford, 1986 (English translation of the 1986 work).
[3] R. Golub, D. Richardson, S.K. Lamoraux, Ultra-Cold Neutrons, Adam Hilger, Bristol, Philadelphia and New York, 1991.
[4] Y. Masuda, T. Kitagaki, K. Hatanaka, M. Higuchi, S. Ishimoto, Y. Kiyanagi, K. Morimoto, S. Muto, M. Yoshimura, Phys. Rev. Lett. 89 (2002) 284801.
[5] A. Saunders, J.M. Anaya, T.J. Bowles, B.W. Filippone, P. Geltenbort, R.E. Hill, M. Hino, S. Hoedl, G.E. Hogan, T.M. Ito, K.W. Jones, T. Kawai, K. Kirch, S.K. Lamoreaux, C. -Y. Liu, M. Makela, L.J. Marek, J.W. Martin, C.L. Morris, R.N. Mortensen, A. Pichlmaier 2, S.J. Seestrom, A. Serebrov, D. Smith, W. Teasdale, B. Tipton, R.B. Vogelaar, A.R. Young, J. Yuan, Phys. Lett. B 593 (2004) 55.
[6] E. Korobkina, B.W. Wehring, A.I. Hawari, A.R. Young, P.R. Huffman, R. Golub, Y. Xu, G. Palmquist, Nucl. Instr. and Meth. A 579 (2007) 530.
[7] A. Fomin, et al., PSI Report TM-14-01-01, 2000.
[8] E. Fermi, J. Marshall, L. Marshall, Phys. Rev. 72 (1947) 192.