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THE MULTISTEP AVALANCHE CHAMBER AS A DETECTOR
FOR THERMAL NEUTRONS

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ABSTRACT

We have investigated the performance of the multistep avalanche chamber in combination with a solid converter foil of gadolinium for detection of $2.4 \text{ \AA}$ thermal neutrons. High spatial resolution, 700 μm FWHM, reasonably good time stability, and low γ -ray sensitivity are among the promising features of this new kind of detector.

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1. INTRODUCTION

Multiwire proportional chambers (MWPCs) are in current use as one- or two-dimensional position-sensitive detectors for thermal neutrons¹⁾. The basis for detection is the capture of a neutron, performed by one of the gas components, followed by the emission of ionizing compounds, such as protons, deuterons, α -particles, etc.

To obtain good detection efficiency combined with a reasonable position resolution and small parallax errors for neutron incident angles different from 90° , it is necessary to pressurize the detector. For a two-dimensional detector over a certain size this imposes serious mechanical problems in the construction.

Instead of using the detector gas as a conversion medium, one can use a converter foil of solid material and detect the emitted conversion electrons by means of a standard gas flow MWPC. To limit the range of the conversion electrons in the detector gas, in many cases several centimetres, one can introduce a solid collimator in front of the foil²⁾. However, the collimator introduces a modulation in the detector's position response, as well as an increased γ -ray background and a decreased neutron detection efficiency is to be expected.

The detector described in this work also uses the standard MWPC and a solid converter foil. The collimation is obtained by introducing an extra gas amplification stage in the chamber, the so-called preamplification stage. When the conversion foil is mounted close to the outer electrode of the preamplification stage, it is preferentially that part of the ionization trail, a few hundred μm , which is closest to the emission point of a conversion electron that is amplified and seen by the MWPC.

2. THE CONVERTER FOIL

A 10 μm thick foil of natural gadolinium was used as a converter; it contained about 15% of gadolinium-157, which is the isotope with the desirable converter properties. A foil enriched with this isotope would therefore have been better suited to our purpose. The conversion in gadolinium consists of an (n,γ) process, where

the neutron is captured, followed by the emission of one or more conversion electrons. The internal conversion probability in gadolinium is so high that each captured neutron creates one or more electrons. The energy spectrum of the conversion electrons has a mean value of 70 keV ³⁾.

The neutron capture cross-section is high, and around 25% of an incoming beam of 2.4 Å neutrons give rise to conversion electrons liberated from the converter foil in back-scattering. Figure 1 shows the theoretical detection efficiencies for gadolinium-157 and for natural gadolinium ²⁾. A strong dependency of the efficiency on wavelength and foil thickness for both transmission and back-scattering can be seen.

3. THE MULTISTEP AVALANCHE CHAMBER

3.1 The photon-mediated avalanche

It has been shown ^{4,5)} that, with a proper choice of gas mixture, it is possible to develop an avalanche between parallel grids with the following characteristics: the lateral spread of the avalanche is such that a sizeable fraction of the resulting electron cloud can be extracted into a following transfer space. The transferred fraction is nearly independent of the position of the electron initiating the avalanche. This permits proportionality between the initial ionization and final transferred charge and prevents modulation of the efficiency as a function of position.

It has been inferred that the emission and absorption of VUV photons play a role in the spread of the avalanche; however other processes, such as electron diffusion and the Penning effect, may also participate.

3.2 The collimation effect

The charge multiplication of an electron in the preamplification stage varies exponentially with its distance from the second preamplification grid. An electron cloud, obtained by preamplification and transfer of the electrons in an ionization trail produced in the preamplification region, will therefore privilege the initial electrons closest to the entrance grid limiting the preamplification gap. When the converter foil is mounted in close contact with this grid, the preamplification mechanism will serve as a kind of collimator for the conversion electrons.

The localization effect can easily be treated quantitatively, using the following simplifying assumptions: the ionization tracks follow straight lines, they are infinitely long, and they are emitted uniformly in space from a point on the entrance grid. Under these conditions one gets a simple expression for the centre of gravity distribution of preamplified and transferred electron clouds ,

$$I(Z) = \frac{1}{1 + \left[\frac{\ln M}{\ell} Z \right]^2} ,$$

where ℓ is the distance between preamplification grids, M is the multiplication factor over the distance ℓ , and Z is the coordinate in a direction parallel to the grids. The formula is accurate within a few per cent for values of $M > 50$. In the case where there is no multiplication the expression is modified to

$$I(Z) = \frac{1}{1 + \left[\frac{2}{\ell} Z \right]^2} .$$

Figure 2 shows $I(Z)$ for $\ell = 3$ mm and different values of M . In the case of $M = 2000$, which corresponds to the working conditions of our detector, we expect a position accuracy of about 1 mm FWHM.

In practice, the ionization tracks created by electrons from the foil converter are neither straight lines nor infinitely long. The energy spectrum of emitted electrons extends down to zero, which implies that a large amount of the tracks have a very limited range, less than a few hundred μm , in the detector gas. This improves the final position accuracy of the detector.

4. EXPERIMENTAL SET-UP

The arrangement of wire planes in the detector is shown in Fig. 3. Two electrodes have been mounted on top of a standard MWPC to provide the preamplification and transfer regions. The preamplification electrode F is a mesh of stainless steel wires, 30 μm in diameter and 500 μm apart. The electrode E is a micromesh of Ni wires, 10 μm in diameter and 100 μm apart. A foil of natural gadolinium G, mounted on an aluminium ring H, 50 mm in diameter, is pressed against the outer electrode in such a way that in the preamplification region the distance between the electrodes E and F is 3 mm, whereas the distance between them at the edges of the

chamber is 5 mm. We have designed the preamplification region in this way to prevent sparks from appearing at the edges during operation. The distance between the electrode E and the MWPC is 3 mm. A is a mylar window which closes the MWPC on the other side, making it gas tight.

The MWPC and associated electronics have been described elsewhere⁶⁾. Briefly, the anode plane (electrode C) is made of gold-plated tungsten wires, 10 μm in diameter and 1.27 mm apart. The two orthogonal cathode planes B and D are made of Cu-Be wires, 100 μm in diameter and 1.27 mm apart. The anode-cathode distance is 5 mm, and the active area of the MWPC is $10 \times 10 \text{ cm}^2$. The bi-dimensional read-out of the MWPC is done with the centre-of-gravity method where, for each avalanche occurring on the anode, the positive induced charge distributions on the two cathode planes are recorded. The cathode wires are connected together 4 by 4 in strips, and each strip is connected to a charge preamplifier having a sensitivity of about 250 mV/pC, a rise-time of 10 ns, and a decay-time of 50 ns^{*)}; the amplified signals are then transmitted via coaxial cables to a CAMAC-based, 10-bit current integrating ADC^{**)}.

All anode wires are connected together; the signal from this plane is recorded in an ADC channel and provides also the gate for the ADC modules after suitable discrimination and shaping. The gate width is 100 ns. A small on-line computer is used to organize the data acquisition and transfer to magnetic tape.

As a gas filling we have used a mixture of argon and acetone in the volume concentration 98-2.

5. CALIBRATION AND DATA HANDLING

A detailed description of the procedure used to calibrate the chains of the preamplifier, coaxial cable, and ADC channel, is given in Ref. 6. The calibration allows us to correct in software for non-linearities in the chains as well as for dispersions between them.

*) Developed at CERN by J.C. Santiard and produced with a hybrid thick film technique by CIT-Alcatel, France.

**) Lecroy, 12-channel ADC, type 2249A.

Let us denote by q_i the effective charge signal on strip S_i , as obtained from the raw data using the above-mentioned calibration procedure. We define the centre-of-gravity of a cluster of adjacent induced charges as the quantity:

$$\bar{S} = \sum (q_i - b) S_i / \sum (q_i - b) ,$$

where b is a bias level, and the sum extends only to positive values of $q_i - b$. A proper choice of bias level allows reduction of the influence of pick-up and electronics noise in the centre-of-gravity determination. In our case a value of $b = 2\%$ of $\sum q_i$ gave satisfying results.

6. EXPERIMENTAL RESULTS

6.1 Introduction

The detector was tested in a $2.41 \text{ \AA}$ monoenergetic neutron beam at the Institut Laue-Langevin (ILL) in Grenoble, France. The beam could be shaped to the desired profile using collimators made of 1 mm sheets of cadmium. The γ -ray background in the surroundings of the detector, measured with a dosimeter, was typically at the level of 6 mrd/h. The chamber was operated at a voltage of +2.20 kV on the anode, and -300 V between the electrodes D and E. The cathodes are grounded; the voltage between E and F is -3.6 kV or less.

6.2 Detection efficiency

The counting rate of the detector was measured for different values of the voltage HV_F on electrode F, in a beam with an intensity of 2000 neutrons/s. The threshold for counting was set just over the electronics noise level. The result is shown in Fig. 4. The background, obtained from counting with the beam off, has been subtracted before plotting the curve. The counting time was 1 min for each point; therefore the uncertainty in the measurement from statistical fluctuations is negligible. We see that no plateau is obtained. The reason is that it was not possible to operate the detector in a stable way with a preamplification voltage high enough to detect the low-range part of the ionization tracks.

It has been shown⁵⁾ that it is possible to detect single electrons after pre-amplification, so with a good detector one should be able to get close to 25% detection efficiency, which is the theoretical value for 2.4 Å neutrons, see Fig. 1. In our case the measured efficiency is around 20% for HV_F equal to -3.85 kV, which was the operational voltage on the preamplification electrode during most of the tests.

6.2 The γ -ray background

On a normal pressurized MWPC for thermal neutrons, where the conversion takes place in the detector gas, one can easily discriminate against unwanted γ -ray events, as these in most cases give rise to much lower energy losses in the detector gas than the neutrons do.

Two factors contribute to a decrease of the γ sensitivity as compared with a normal proportional chamber:

- Only the electrons extracted from the entrance window (F, Fig. 3) are counted.
- Only the Compton electrons back-scattered in the gadolinium foil are counted.

We wondered also if the detected pulses showed a difference between γ 's and neutrons. In a detector like ours, one should not expect to see much difference, in both cases it is only a part of an ionization track, created by a conversion electron, that is detected. It turns out, however, that there is a possibility to reduce the γ -ray background, although at the price of reduced detection efficiency. Figure 5 shows a typical anode pulse spectrum as obtained with our detector in the normal working conditions. The cut at the lower end is introduced by the electronic threshold. The cut at the higher end is set by the software program, which does not accept events that have given overflow in any of the ADC channels⁶⁾. The beam is collimated to 350 μm in the direction along the anode wires. Figures 5b, c and d show the detector response in that direction for each of the three intervals shown in Fig. 5a. It is seen that an increase of the electronic threshold to some extent decreases the number of counts outside the peak. The γ -ray events seem to appear mainly in the low end of the anode pulse spectrum.

The sensitivity to γ -rays was also tested by a comparison between the detector responses obtained with and without a 5 cm thick lead block positioned in the neutron beam. No significant difference could be observed between the two cases, showing that the γ -rays are coming from the general background of the area. Further tests are needed to get more quantitative information about the sensitivity for different γ -ray energies.

6.3 Position accuracy

From Fig. 5 it can also be seen how the position accuracy of the detector varies for different selections in the anode pulse spectrum. The bin width in the spectra is 250 μm . The best result, 650 μm FWHM, is obtained for the interval II. The pulses are here sufficiently high to exclude the contribution of the electronics noise in the centre-of-gravity determination. For the interval III the accuracy decreases; note the high tails in the spectrum. The reason is that conversion electrons, which are scattered back towards the gadolinium foil, or emitted at angles far from the direction orthogonal to the foil, do not localize the emission point very well, and also tend to give larger pulses because of a larger ionization close to the electrode F.

The following results are obtained without any selection in the anode pulse spectrum. In all cases where values for the position accuracy are given, these values would improve by around 100 μm if only events from the interval II were taken into account.

The position accuracy was measured for different values of HV_F . The results are shown in Fig. 6, which is a plot of the FWHM of the position spectra against HV_F . We see the tendency mentioned above that the position accuracy increases with increasing preamplification voltage. The results shown from now on have all been obtained with $HV_F = -3.85$ kV.

6.4 Variations of detector response with position and time

For many applications it is of great importance that the detection efficiency of the chamber remains stable during several days. Variations in the efficiency

for different positions in the detector can be corrected for in the software data handling, if the time stability is good. That it is possible to obtain good time stability with our detector is not obvious, since the electronic threshold for detection is not positioned well below the pulse height spectrum. We have measured the counting rate in the chambers, scanning the sensitive area in the direction along the anode wires, Fig. 7a, and in the orthogonal direction, Fig. 7b. The counting time was one minute for each point, giving negligible statistical fluctuations in the measurement. After one hour, one of the scans was repeated, indicated by open dots in Fig. 7b. The time stability seems reasonably good, but further tests, over many days, are needed before any definite conclusion can be made.

6.5 Linearity and position response

In the direction along the anode wires the linearity of the detector response was expected to be good. That this is the case can be seen from Fig. 8a, which shows a scan over the active area in steps of 5 mm. In Fig. 8b are shown the corresponding position accuracies. A mean value of around 700 μm FWHM is obtained. A scan with steps of 500 μm in the orthogonal direction is shown in Fig. 9. Also here we have a mean value for the accuracy of 700 μm . The anode wire structure, wire distance 1.27 mm, introduced no modulation in the linearity, Fig. 9a, and only a small modulation in the value of the local accuracy, Fig. 9b. This can be explained from the above-mentioned lateral spread in the electron avalanches after preamplification. For each event, avalanches will appear on more than one anode wire at the same time, and this effect improves the linearity of the detector. The scans of Figs. 8 and 9 have been made with beams collimated to 350 μm .

A few tests were made with other beam profiles. Figure 10a shows the two-dimensional response, when the beam enters the detector through two holes in a cadmium sheet, 600 μm in diameter and 2.5 mm apart. In Fig. 10b is shown for the same events, the detector response in the direction along the anode wires. The bin width is 250 μm . The two peaks are completely resolved.

A cadmium sheet with a hole pattern as shown in Fig. 11a was mounted in the beam. The diameter of the holes was 600 μm . The detector response is shown in Fig. 11b.

7. CONCLUSIONS

The combination of the multistep avalanche chamber with a converter of gadolinium-157 turns out to be promising for thermal neutron detection. The detection of the back-scattered conversion electrons reduces the Compton electron background expected from a solid converter.

The chamber is operated with gas at atmospheric pressure, which prevents problems with outgasing, purity and high pressure. The two-dimensional spatial resolution is around 700 μm FWHM. The detection efficiency is mainly determined by the converter foil, and is measured to be around 20% for 2.4 $\text{\AA}$ neutrons. Higher values, close to 50%, are feasible, by the application of converters enriched in gadolinium-157. The preliminary tests indicate that the background of γ -rays can be kept at a reasonably low level. Also the time stability seems to be good, although further tests are needed to clarify this point completely.

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Figure captions

- Fig. 1 : Theoretical detection efficiencies for gadolinium-157 and for natural gadolinium²⁾.
- Fig. 2 : Theoretical distributions of the centre of gravity of preamplified and transferred electron clouds for different values of the amplification factor M. The curves 1 to 4 correspond to the M values 1, 50, 200, and 2000.
- Fig. 3 : Schematic view of the detector. A is a mylar window; B, C, and D constitute a standard MWPC; E and F are the preamplification electrodes; G is a gadolinium foil mounted on an aluminium ring H; I is an incoming neutron, converting to an electron that ionizes along the track J.
- Fig. 4 : Counting rate in the detector versus preamplification voltage. No plateau is obtained. The beam intensity was 2000 neutrons/s.
- Fig. 5 : a) Typical anode pulse spectrum. The spectrum is cut at the lower side by an electronic threshold. At the higher side we cut the spectrum in order to eliminate those pulses which are too high and give rise to overflow in the ADCs. The spectrum is divided into three intervals corresponding to the events in figs. 4 b, c and d.
- b,c,d) Detector response in the direction along the anode wires for different intervals of the anode pulse spectrum. Bin width 250 μm .
- Fig. 6 : Variation of the position accuracy with the preamplification voltage.
- Fig. 7 : Variation of the counting rate in the detector a) along the anode wires, and b) in the orthogonal direction, indicated by closed dots. A scan made one hour later is indicated by open dots. The time stability seems to be good.

- Fig. 8 : The detector response for different positions of the beam in the direction along the anode wires, showing a) the linearity and b) the spatial resolution. A mean value of 700 μm FWHM is obtained.
- Fig. 9 : The detector response for different positions of the beam in the direction orthogonal to the anode wires, showing a) the linearity and b) the spatial resolution. A mean value of 700 μm FWHM is obtained.
- Fig. 10 : The detector response for a beam collimated through two holes of 600 μm diameter and 2.5 mm apart, showing a) the response in two dimensions and b) in the anode wire direction. The scales are 20 mm and the bin width 250 μm .
- Fig. 11 : a) The pattern ILL drilled in the cadmium sheet as a series of holes, which are 600 μm in diameter.
b) The detector response for neutrons going through the holes.

a)

b)

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11