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Effect of adding Ar gas on the pulse height distribution of BF_3-filled neutron detectors

M PADALAKSHMI and A M SHAIKH*
Solid State Physics Division, Bhabha Atomic Research Centre, Mumbai 400 085, India
*Corresponding author. E-mail: shaikham@barc.gov.in

Abstract. Boron trifluoride (BF_3) proportional counters are used as detectors for thermal neutrons. They are characterized by high neutron sensitivity and good gamma discriminating properties. Most practical BF_3 counters are filled with pure boron trifluoride gas enriched up to 96% ^{10}B. But BF_3 is not an ideal proportional counter gas. Worsening of plateau characteristics is observed with increasing radius due to impurities in gas. To overcome this problem, counters are filled with BF_3 with an admixture of a more suitable gas such as argon. The dilution of BF_3 with argon causes a decrease in detection efficiency, but the pulse height spectrum shows sharper peaks and more stable plateau characteristics than counters filled with pure BF_3. The present investigations are undertaken to study the pulse height distribution and other important factors in BF_3+Ar filled signal counters for neutron beam applications. Tests are performed with detectors with cylindrical geometry filled with BF_3 gas enriched in ^{10}B to 90%, and high purity Ar in different proportions. By analysing pulse height spectra, a value of 6.1 ± 0.2 has been obtained for the branching ratio of the ^{10}B(n,α) reaction.

Keywords. Gas-filled proportional counters; BF_3-filled neutron detectors.

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1. Introduction

Boron trifluoride (BF_3) proportional counters are used as detectors for thermal neutrons. They are characterized by high neutron sensitivity and good gamma discriminating properties. The neutron detection is performed by the reaction $^{10}B(n,\alpha)^7Li$ which has cross-section of 3840 barns for thermal neutrons. The Q-value of the reaction 2.31 MeV or 2.78 MeV is imparted to the reaction products ^{7}Li and α. These particles then ionize the gas in the counter producing an electrical signal. Under ideal conditions two sharp peaks corresponding to Q-values would arise in the pulse height spectrum. But BF_3 is not an ideal proportional counter gas. Worsening of plateau characteristics results with increase in cathode diameter and it is not possible to obtain good characteristics in counters with gas filled at 60 cm Hg and diameters more than 3.8 cm [1,2]. This may be due to fluctuations of the number of initial ion pairs produced due to wall effects and fluctuation of the gas amplification due to electron capture by the impurities in the gas or to saturation effects because of the space charge at the anode wire [3]. To overcome this problem, counters are filled with BF_3 with an admixture of a more suitable gas such as argon. The dilution of BF_3 with argon causes a decrease in detection efficiency, but the pulse height spectrum shows sharper peaks and more stable plateau characteristics than counters filled with pure BF_3. Large dimension detectors filled with various high pressures of BF_3+Ar mixtures have been used for cosmic ray monitoring [1]. Low pressure counters filled with up to 5 cm Hg pressure of BF_3 with sufficiently high argon pressure have been used for neutron beam applications [4]. The present investigations are undertaken to study the pulse height distribution and other important factors in BF_3+Ar filled signal counters for neutron beam applications. The analysis of pulse height spectra for obtaining the branching ratio of the $^{10}B(n, \alpha)$ reaction is also reported.

2. Experimental

Tests are performed on the detectors with cylindrical geometry made of brass cathode 25 mm Ø, anode of 25 μm Ø tungsten wire with sensitive length of 275 mm. The electronic testing set-up consists of a low noise charge sensitive pre-amplifier, spectroscopy amplifier, and a PC-based multi-channel pulse height analyser with 10 V-1 K-ADC calibrated to 10 mV/ch. The anode potential is obtained using a stable high voltage supply with an output variable 0–2500 V DC, positive at a current drain of 0 to 1 mA. The linearity and gain of the entire electronics system are checked using a precision pulse generator connected to the test input of the pre-amplifier. In order to attain optimum counter performance, durability and stability of operation, detectors after assembly are evacuated and baked at 150°C for ~100 h. The purified BF_3 gas generated from $CaF_2 \cdot BF_3$ complex enriched in ^{10}B to 90%, and high purity Ar gas is used for filling. Counters filled with pure BF_3 at 1 cm Hg to 60 cm Hg pressure and those filled with mixture of BF_3 with Ar up to 110 cm Hg pressure have been studied. Measurements are taken on a number of detectors with similar geometry to check reproducibility of the results and for better statistics. The spectra are recorded using Pu–Be source with the surface neutron flux of 150 nv and gamma background of 15 mR/h, amplifier time constant of 3 μs and by adjusting anode voltage, a pulse of ~2 volts around channel no. 200 is obtained.

3. Results and discussion

Figure 1 shows the pulse height distribution curves of the counters filled with various proportions of BF_3 and Ar. The detectors filled with only BF_3 show clustering of ionizing events at all pressures (figures 1a and 1d). As the proportion of Ar added to BF_3 increases, the pulse height spectrum gets more resolved; the two main pulses along with those due to wall effect appear (figures 1b and 1e), which are seen as two steps on the lower energy side of the curve. As the pressure of Ar is increased further, the wall effect reduces and the two peaks get separated completely with excellent resolution as shown in figures 1c and 1f. It is apparent that only small

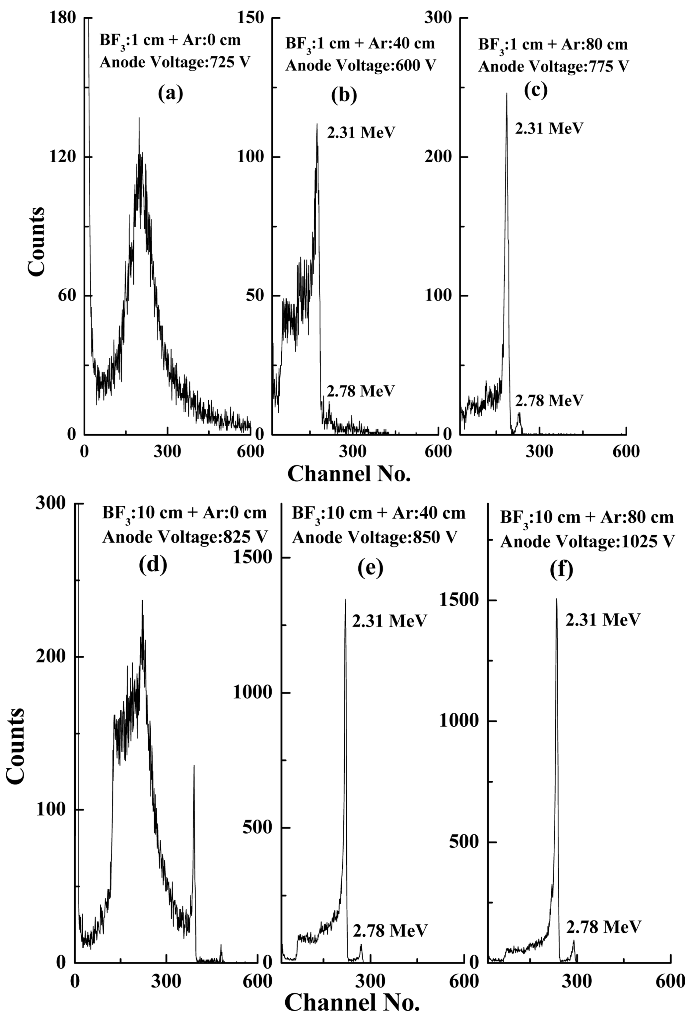

Figure 1. Pulse height distribution curves of counters with various BF_3 and Ar pressures.

amount of BF_3; say at 1 cm to 10 cm of Hg and large amount of Ar exceeding 60 cm Hg only keeps the ionizing track lengths short compared with the counter dimensions to give a well-resolved pulse height spectrum.

The pulse height spectra show energy resolutions of 7% and 6%, 5.7% and 2.5% and 3.7% and 3.3% for the two main peaks with argon at 80 cm Hg added to BF_3 at 1, 5 and 10 cm of Hg fill pressure respectively. Increase in BF_3 filling beyond 10 cm of Hg pressure causes degradation of resolution of 2.31 MeV peak. This may be because apart from wall effect, at high pressures pulses of smaller than maximum size are formed when all electrons produced are not collected due to negative ion formation or columnar recombination. Traces of electronegative impurities can also cause the degradation of pulse height spectrum. It shows that for the signal

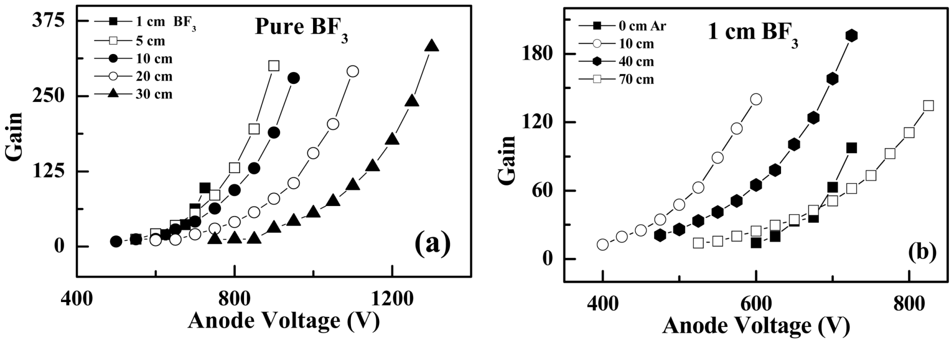

Figure 2. Variation of gas gain with applied voltage for various pressure fillings of BF_3 + Ar.

detectors with cathode diameter around 25 mm, BF_3 fillings in the pressure range 1 to 10 cm Hg with addition of Ar more than 60 cm Hg are necessary. In order to calculate the branching ratio of $^{10}B(n,\alpha)^7Li$ reaction a few experimental runs were made to collect the spectra for these detectors. The branching ratio is obtained by taking ratio of the sums of the number of pulses in the 2.78 MeV peak to the total number of pulses collected. The value obtained is 6.1 ± 0.2, which agrees with values reported in the literature [1,4].

Figure 2 shows gas gain as a function of applied anode voltage for detectors filled with pure BF_3 and BF_3 + Ar mixture. It can be seen from the graph that the gas gain (M) is an exponential function of the applied voltage in the range of $10 < M < 375$. The gain below 10 is not recorded because the fluctuations in avalanche affect the signal to noise ratio significantly. The maximum gain recorded for each detector represents the highest stable gain within the region of proportionality. In the case of detectors filled with pure BF_3 the operating voltage increases with increase in fill pressure to attain the same gain (figure 2a), whereas in the detectors filled with BF_3+Ar mixture the behaviour is different. As seen from figure 2b, a gas gain of $\sim$100 is obtained when the detector is filled with 1 cm Hg pressure of BF_3 at an anode voltage of 725 V. With addition of Ar at 10 cm Hg pressure the same gain is obtained at lower anode voltage of 575 V. This is due to increase in the number of ion pairs produced due to addition of Ar and the effective energy required to produce an ion pair in the BF_3 + Ar mixture (w = 26.80 eV) is lower compared to that for pure BF_3 gas (w = 35.5 eV). Even though the overall gas pressure has increased to 11 cm Hg, the $(E/p)_{\rm min}$ value (where E is the electric field and p the gas pressure) required for gas multiplication is lower compared to that for 1 cm Hg pressure of pure BF_3. This condition prevails till the Ar pressure reaches 70 cm Hg. The gas gain curve for the detector filled at this pressure almost overlaps that filled with pure BF_3. The same gain is obtained at higher voltages with further increase in Ar pressure. At these pressures the $(E/p)_{\rm min}$ is greater compared to that for pure BF_3 at 1 cm Hg pressure. Similar behaviour has also been observed for other high-pressure fillings of BF_3.

Figure 3 shows neutron plateau characteristic curves for various BF_3 + Ar mixtures. The efficiency of the detector increases with increase in BF_3 pressure and plateau shift to higher operating anode voltage (figure 3a). For 1 cm Hg pressure

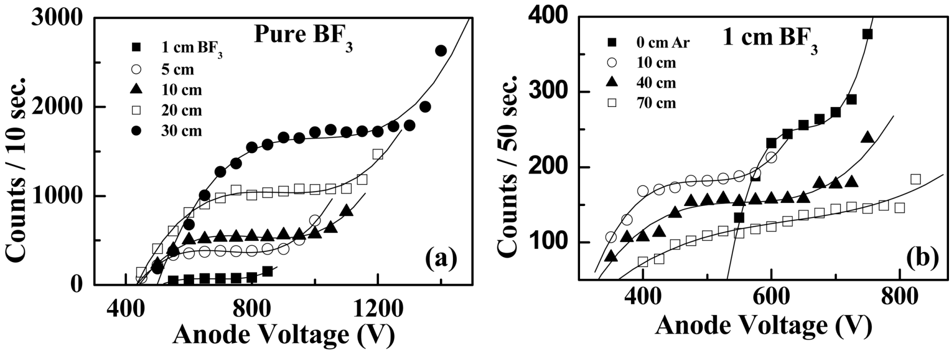

Figure 3. Plateau characteristics curves for counters filled with various pressures of BF_3 and Ar.

of BF_3 efficiency of the detector decreases with addition of Ar. The plateau shifts towards the lower voltages up to an Ar pressure of 30 cm Hg and then to higher voltages with improvement in plateau slope (figure 3b). Similar results are also obtained with gas pressures up to 30 cm Hg of BF_3. This may also be explained on the basis of reasons given in description of gain characteristics in above paragraph. In the detector with 10 cm of Hg BF_3 pressure, the plateau slope improves from 3.1 to 1.2% with addition of Ar up to 100 cm of Hg pressure.

4. Conclusions

The present investigations have shown that excellent pulse height distribution spectra can be obtained with fillings up to 10 cm BF_3 and 60 cm Ar. With 25 μm anode and 25 mm cathode, these counters have stable plateau and can be operated around 800 V with gas gain up to 150 for neutron beam applications. By analysing pulse height spectra, a value of 6.1 ± 0.2 has been obtained for the branching ratio of the $^{10}B(n,\alpha)$ reaction.

References

[1] I L Fowler, *Rev. Sci. Instrum.* **34(7)**, 731 (1963)

[2] G F Knoll, *Radiation detection and measurement*, II edition (John Wiley and Sons, 1989)

[3] R Cervellati and A Kazimierski, *Nucl. Instrum. Methods* **60**, 173 (1968)

[4] I O Andersson and M Malmskog, Aktiebolaget Atomenergi (Sweden) Report AE-84 (1962)