Chapter 9  Neutron Detectors

9.1. Slow neutron detection

A. Popular nuclear reactions

Slow neutrons are in the energy range below 0.5 eV. There are common requirements for slow neutron detection. As in photon detection, the interaction cross section must be as large as possible to achieve a high efficiency. Neutrons always produce secondary gamma-rays by interacting either with detector materials or with surrounding materials. Thus, the Q-value of the interaction should be large to make the gamma-ray discrimination easy. The third requirement is that the kinetic energies of the interaction products should be fully absorbed.

The three useful interactions are $^{10}$B(n,α), $^{6}$Li(n,α) and $^{3}$He(n,p). The Q-values are so large (compared to the neutron energy) that the interaction products cannot give energy information on the detected neutron. Thus, these detectors are useful for the pulse counting mode and a time-of-flight spectroscopy system must be employed if slow neutron spectroscopy is intended. The reaction products are emitted in opposite directions to conserve the linear momentum and the energy of each product can be calculated by conservation of energy and momentum.

<table>
<thead>
<tr>
<th></th>
<th>$^{10}$B(n,α)</th>
<th>$^{6}$Li(n,α)</th>
<th>$^{3}$He(n,p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance and cross section</td>
<td>19.9 % 3837 barns</td>
<td>7.6 % 937 barns</td>
<td>0.014 % 5330 barns</td>
</tr>
<tr>
<td>Products and Q-value</td>
<td>$^{7}$Li+α (2.79 MeV) (6 %) $^{7}$Li$^*$+α (2.31 MeV) (94 %)</td>
<td>$^{3}$H+α (4.78 MeV)</td>
<td>$^{3}$H+p (0.76 MeV)</td>
</tr>
<tr>
<td>Kinetic E</td>
<td>α: 1.47 MeV $^{7}$Li: 0.84 MeV</td>
<td>α: 2.05 MeV $^{3}$H: 2.73 MeV</td>
<td>p: 0.57 MeV $^{3}$H: 0.19 MeV</td>
</tr>
</tbody>
</table>

B. Boron-based detectors

The most famous type of boron-based neutron detector is the BF$_3$ proportional counter. In this detector, BF$_3$ gas acts as both a proportional gas and a neutron detection material. Among various types of boron-containing gases, BF$_3$ has high concentration of boron and its gas multiplication performance is good as well. The intrinsic efficiency of a 30 cm long detector
(96% enriched $^{10}$B) filled to 600 torr is 92% at thermal neutron energies (25 meV). Fig. 9.1 shows pulse height spectra from a BF$_3$ detector. Depending on the energy deposition of each product ion, the total deposited energy inside the gas volume changes.

**C. $^6$Li-based detectors**

Because a lithium-containing gas is not available, scintillation detectors are common as lithium-based slow neutron detectors. LiI is chemically similar to NaI, and therefore its scintillation performance is reasonably good. As an activator for LiI, Eu is doped.

The thickness of a LiI(Eu) crystal is good enough to fully stop the neutron interaction products (alpha particle and triton). Thus, each neutron interaction event can make a signal pulse height equivalent to 4.78 MeV. When a gamma-ray with similar energy makes an interaction of full-energy deposition, the resultant pulse height is the same as the pulse height of the neutron event. Accordingly, the gamma-ray discrimination of LiI(Eu) neutron detectors are inferior to gas neutron detectors.

**D. $^3$He-based detectors**

Due to the natural property of helium, a gas proportional counter is the most popular type. Compared to the $^{10}$B(n,$\alpha$) interaction, the $^3$He(n,p) reaction has a bigger cross section, which makes an $^3$He proportional counter an attractive alternative to a BF$_3$ proportional counter. The lower Q-value of the $^3$He(n,p) reaction makes gamma-ray discrimination more difficult than for a BF$_3$ counter.

**9.2. Fast neutron detection**

![Fig. 9.2. Principle of the moderator-based fast neutron detector.](image)

![Fig. 9.3. A spherical neutron dosemeter.](image)

**References**

Problems

1. Suppose a proportional counter filled with BF₃ gas is exposed to a slow neutron radiation field and its pulse height spectra are collected.
   (a) Write down the neutron detection reaction and the reaction products.

   (b) Pulse height spectra are shown below. Briefly explain how the features “(1)” and “(2)” are produced.

![Pulse height spectra with features labeled (1) and (2)](image-url)