7.3. THERMAL NEUTRON DETECTION

Table 7.3.2.1. *Neutron capture reactions used in neutron detection*

n = neutron, p = H^+ = proton, t = $^3H^-$ = triton, $\alpha = {}^4H^+$ = alpha, e^- = electron

Capture reaction	Cross section at 1 Å (barns)	Secondary-particle energies (MeV)
$^3He + n \rightarrow t + p$	3000	t 0.20 p 0.57
$^6Li + n \rightarrow t + \alpha$	520	t 3.74 α 2.05
$^{10}B + n \rightarrow {}^7Li^* + \alpha$ (93%) $\hookrightarrow {}^7Li + \gamma$ $\rightarrow {}^7Li + \alpha$ (7%)	2100	α 1.47 ^7Li 0.83 γ 0.48 α 1.78 ^7Li 1.01
$^{157}Gd + n \rightarrow Gd^*$ $\hookrightarrow \gamma$ + conversion electrons	74000 (^{nat}Gd: 17000)	e^- spectrum 0.07 to 0.182 γ spectrum up to 8
$^{235}U + n \rightarrow$ fission fragments	320	Fission fragments up to 80

There are two modes of operation.

In the case of *direct collection of charges*, the 25 000 electrons corresponding to one neutron capture (*primary electrons*) are collected by the anode in about 100–500 ns, and generate an input pulse in the charge preamplifier (see Section 7.3.4).

If the electrical field created by the high voltage applied to the anode exceeds a critical value, the electrons will be accelerated sufficiently to produce a cascade of ionizing collisions with the neutral molecules they encounter, the new electrons liberated in the process being called *secondary electrons*. This phenomenon, *gas multiplication*, occurs in the vicinity of the thin wire anode, since the field varies as $1/r$. The avalanche stops when all the free electrons have been collected at the anode. With proper design, the number of secondary electrons is proportional to the number of primary electrons. For cylindrical geometries, the multiplication coefficient M can be calculated (Wolf, 1974). This type of detection mode is called the proportional mode. It is very commonly used because it gives a better signal-to-noise ratio (see Section 7.3.4).

A few critical remarks about gas detectors:

(i) Some gases have a tendency to form negative ions by the attachment of a free electron to a neutral gas molecule, giving a loss of detector current. This effect is negligible for ^3He but it limits the use of $^{10}BF_3$ to about 2 atmospheres pressure, although traces of gases such as O_2 or H_2O (*e.g.* detector materials and wall outgasing) are often the reason for loss by attachment.

(ii) Pure ^3He and $^{10}BF_3$ gas detectors are practically insensitive to γ radiation. This is no longer the case when additional gases, which are necessary for ^3He, are used, although the polyatomic additives C_3H_8 and CF_4 are much better than the rare gases Kr, Xe, and Ar (Fischer, Radeka & Boie, 1983).

(iii) For various reasons (the price of ^3He and $^{10}BF_3$ and the toxicity of BF_3), neutron gas detectors are closed chambers, which must be leak-proof and insensitive to BF_3 corrosion. The wall thickness must be adapted to the inside pressure, which sometimes implies a rather thick front aluminium window (*e.g.* a 10 mm window for a 16 bar ^3He gas position-sensitive detector; aluminium is chosen for its very good transmission of neutrons, about 90% for 10 mm thickness).

7.3.3.2. *Detection via solid converter and gas ionization: the foil detector*

This mode of detection is generally used for monitors. In a typical design, a ^{10}B deposit of controlled thickness, for example $t = 0.04\,\mu m$ giving a capture efficiency of 10^{-3} at $\lambda = 1$ Å, is made on a thin aluminium plate (see Fig. 7.3.3.2). One of the two particles (α, Li) produced in the solid by the capture reaction is absorbed by the plate; the other escapes and ionizes the gas. The electrons produced are collected by the aluminium plate, itself acting as the anode, or by a separate anode wire, allowing the use of the proportional mode. The detection efficiency is proportional to the deposit thickness t, but t must be kept less than the average range r of the secondary particles in the deposit (for ^{10}B, $r_\alpha = 3.8\,\mu m$ and $r_{Li} = 1.7\,\mu m$), which limits the efficiency to a maximum value of 3–4% for $\lambda = 1$ Å. The fraction of the secondary particle energy that is lost in the deposit reduces the detector current, *i.e.* the signal-to-noise ratio, and worsens the amplitude spectrum (see Section 7.3.4).

7.3.3.3. *Detection via scintillation*

In the detection process *via* scintillation (see Table 7.3.3.1), the secondary particles produced by the neutron capture ionize and excite a number of valence-band electrons of the solid scintillator to high-energy states, from which they tend to decay with the emission of a light flash of photons detected by a photomultiplier [see Fig. 7.3.3.3(*a*)]. A number of conditions must be satisfied:

(i) The scintillation must be immediate after the neutron-capture triggering event.

(ii) The scintillation decay time must be short. It depends on materials, and is around 50–100 ns for lithium silicate glasses.

(iii) A large fraction of the energy must be converted into light (rather than heat).

(iv) The material must be transparent to its own radiation.

Most thermal neutron scintillation detectors are currently based on inorganic salt crystals or glasses doped with traces of an activating element (Eu, Ce, Ag, *etc.*) (extrinsic scintillators). (A plastic scintillator might be considered to be a solid organic solution with a neutron converter.)

The use of extrinsic scintillators (Convert & Forsyth, 1983), although less efficient energetically, permits better decoupling of the energy of the photon-emitting transition (occurring now in the activator centres) from that of the valence-band electron excitation or ionization energy. The crystal or glass is then transparent to its own emission, and the light emitted is shifted to a wavelength better adapted to the following optical treatment.

references