10.3.2.4 X-ray detectors

10.3.2.4.1 Solid-state detectors

The most common solid-state detector is the Si(Li) detector; it consists of a disk of Si which is suitably doped and with Li diffused into the central region. A reverse-bias potential is applied across the surfaces. When an X-ray photon is absorbed in the central region, it produces a number of *electron-hole pairs* proportional to the energy of the absorbed photon. These electrons and holes are attracted to the opposite surfaces and constitute an electrical pulse.

Because of defects, impurities and other loss mechanisms, the number of electron-hole pairs shows some statistical variation for constant photon energy. This amounts to broadening the pulse amplitude distribution of the characteristic X-ray photons and can be expressed in terms of energy resolution. The equation for the statistical contribution Γ(s), to the full width at half maximum of the pulse amplitude distribution, is given by the relationship

$$\Gamma(s) \cong 2.35\sqrt{F\varepsilon E}$$

where F is a dimensionless factor, the *Fano factor*, whose value is estimated to be between 0.1 and 0.13 for Si(Li), E is the photon energy in eV and ε is the energy per electron hole pair or per electron ion pair. For a photon energy of 6000 eV, the value of Γ(s) would be about 125 eV.

10.3.2.4.2 Multichannel analyzer

In energy-dispersion X-ray analysis the *multichannel analyzer* is an instrument used to store information from the Si(Li) detector. Each channel (memory cell) corresponds to a small energy increment, ΔE. Each pulse from the detector is stored in the appropriate channel according to the amplitude of the pulse (e.g., the photon energy).

10.3.2.4.3 Gas-filled X-ray detectors

Gas filled X-ray detectors consist of a cylindrical cathode with a window, an axial wire anode and an ionizable gas. The gas may be continuously replenished giving a *flow-through detector* or the detector may be sealed. In the high electric field surrounding the anode wire, electron multiplication occurs through a process of *gas amplification*. The gain of this process is defined as the number of electrons collected on the anode wire for each primary electron produced in the original ionizing event. For X-rays having energies higher than the excitation potential of the *detector gas*, the spectral responsivity function has a second peak, in addition to the main peak, that is called the *escape peak*. The escape peak has a mean pulse height proportional to the difference between the photon energy of the incident X-rays and of the spectral characteristic line of the detector gas. A *quenching gas*, a molecular gas, is added to the detector gas in order to neutralize the detector gas ions and to absorb secondary electrons as well as UV radiation resulting from neutralization of detector gas ions.

According to the potential applied to the anode, the detector can work as an *ionization chamber*, *proportional counter* or *Geiger counter*. An ionization chamber is a gas-filled X-ray detector without any gas amplification. In proportional counters the electric potential is high enough for the gain to reach a value in the range from 10^2 to 10^5. Each electron produced by the initial photo-ionization causes one avalanche. Since the number of avalanche events is proportional to the energy of the incident photons, the charge collected by the anode is proportional to the X-ray photon energy. The *proportional gas-scintillation counter* consists of a proportional counter coupled to an ultraviolet sensitive photomultiplier tube. Initial electrons produced by the interaction of the high-energy photon with the counter fill-gas are accelerated by a high electric field where they acquire sufficient energy to excite the noble gas atoms. The resulting UV radiation is observed by a photomultiplier tube. The statistical uncertainties in the number of ion-electron pairs formed and gas gain result in a *pulse amplitude distribution* where photons of constant energy are absorbed. *Detector resolution*, Γ, (in eV) is the full width at half maximum of its pulse amplitude distribution, given empirically by

$$\Gamma \cong 2.35 \sqrt{1.7\, \varepsilon E}$$

where 2.35 is the breadth at half maximum of the normal error curve; the factor 1.7 is a property of the detector and is empirically determined, ε is the ionization energy, 15.8 eV for argon gas, and E is the photon energy. For 6000 eV photons, Γ becomes $\cong$ 950 eV. In *Geiger counters*, gas amplification reaches saturation and proportionality no longer exists. The output signal does not depend on the incident energy. The time taken for the counter to recover from the saturation is called *deadtime*.