R1.2 Radiation spectrometry

R1.2.1 Crystal scintillation spectrometry

When the energy of beta or gamma radiation is dissipated within some materials known as scintillators, light is produced in an amount proportional to the energy dissipated. This quantity of light may be measured by suitable means, and is proportional to the energy absorbed in the scintillator. The light emitted under the impact of a gamma photon or a beta particle is converted into an electric output pulse by a photomultiplier. Scanning of the output pulses with a suitable pulse-height analyser results in an energy spectrum of the source.

The scintillators most commonly used for gamma spectrometry are single crystals of thallium-activated sodium iodide. Gamma-ray scintillation spectra show one or more sharp, characteristic photoelectric peaks, corresponding to the energies of the gamma radiation of the source. They are thus useful for identification purposes and also for the detection of gamma-emitting impurities in a preparation. These peaks are accompanied by other peaks due to secondary effects of radiation on the scintillator and its surroundings, such as backscatter, positron annihilation, coincidence summing, and fluorescent X-rays. In addition, broad bands known as the Compton continua arise from the scattering of the gamma photons in the scintillator and in surrounding materials. Calibration of the instrument is performed with the use of reference preparations of radionuclides whose energy spectra have been characterized. The shape of the spectrum produced will vary with the instrument used, owing to such factors as differences in the shape and size of the crystal, in the shielding materials used, the distance between the source and the detector, and in the types of discriminator employed in the pulse-height analysers. When using the spectrum for identification of radionuclides it is therefore necessary to compare the spectrum with that of a reference preparation of the radionuclide obtained in the same instrument under identical conditions.

Certain radionuclides, for example, iodine-125, emit characteristic X-rays of well-defined energies that will produce photoelectric peaks in a suitable gamma spectrometer. Beta radiation also interacts with the scintillators, but the spectra are continuous and diffuse and generally of no use for identification of the radionuclide or for the detection of beta-emitting impurities in a radiopharmaceutical preparation.

R1.2.2 Semiconductor detector spectrometry

Gamma-ray spectra may be obtained using solid-state detectors. The peaks obtained do not suffer to the same extent the broadening shown in crystal scintillation spectrometry, and the resolution of gamma photons of similar energies is very much improved. However, the efficiencies of such detectors are much lower.

The energy required to create an electron-hole pair or to promote an electron from the valence band to the conduction band in a semi-conductor is far less than the energy required to produce a photon in a scintillation crystal. In gamma-ray spectrometry a high purity germanium (HPGe) detector can provide an energy resolution of 0.14-0.18 % for the 1.33 MeV photon of cobalt-60.

R1.2.3 Liquid scintillation counting

For beta-emitters like ^{35}S, ^{14}C and ^{3}H, where self-absorption of the low-energy beta particles is significant, the preferred counting method is by liquid scintillation, which can occasionally be employed also for emitters of X-rays, alpha-particles, and gamma-rays. If the sample to be counted is dissolved in, or mixed with, a solution of an appropriate scintillator material, the decay energy from the sample is converted into light photons. These are sensed by a photomultiplier, which converts them into an electric pulse, whose intensity is proportional to the energy of the initial radiation. Thus, simultaneous counting of several radionuclides differing in the energy of emitted radiation can be effected with suitable discriminators (pulse-height analysers), provided the energy separation is adequate. Detection efficiencies approaching 95 % for ^{14}C and 60 % for ^{3}H are reached because self-absorption is minimized.

The scintillator (to check the chemical) solute usually consists of a polycyclic aromatic compound, such as p-terphenyl or 2,5-diphenyloxazole (primary solute), together with a secondary solute, such as 1,4-di[2-(4-methyl-5-phenyloxazole)]benzene (Dimethyl-POPOP), that shifts the wavelength of the light emitted to match the highest sensitivity of the photomultiplier tube. Water-immiscible solvents, such as toluene, or water-miscible solvents, such as dioxan, can be used. To facilitate the counting of aqueous solutions, special solvents have been developed. Alternatively, samples may be counted as suspensions in scintillator gels. As a means of attaining compatibility and miscibility with aqueous specimens to be assayed, many additives, such as surfactants and solubilizing agents, are also incorporated into the scintillator. For accurate determination of sample radioactivity, care must be taken to prepare a sample that is truly homogeneous. The presence of impurities and colour in the solution causes a decrease in the number and energy of photons reaching the photomultiplier tube; such a decrease is known as quenching. Accurate radioactivity measurement requires correcting for count-rate loss due to quenching. Solutions containing organic scintillators are prone to photo-excitation and samples may need to be prepared in subdued light and kept in darkness before and during counting process.