CHAPTER II

PRINCIPLE OF LIQUID SCINTILLATION COUNTER

2.1 Principle of Liquid Scintillation Counting. (18,19,20,21,22,23,24,25,26,27)

Scintillation counting is one of the methods for measuring radiation. This method has been used since 1903 but in a rather limited form. Only after the development of photomultiplier tubes and the discovery of organic scintillators, the method has been widely applied.

Organic scintillators are chemical compounds which have the property of absorbing radiant energy. The absorption of this energy by the scintillator results in the formation of excited atoms or nuclides which then return rapidly to the normal or ground state, releasing photons (light energy) and heat. Scintillators are transparent to their emitted light which is in the ultraviolet or visible range. The number of photons emitted is linearly related to the absorbed radiant energy.

The term "Liquid Scintillation Counting" is used when the scintillator and the radioactive material to be assayed are dissolved in a suitable solvent.

The energy of the radiation emitted from a radioactive source is first absorbed by the solvent molecules, causing them to become excited. This excitation energy is propagated within the solvent and transferred to the solute (scintillator), causing the scintillator molecules to become excited and when they return to their ground states they emit photons (light).

Two scintillators are often used together. The secondary scintillator is added into the primary scintillator to improve the counting efficiency.

A primary scintillator should exhibit the following characteristics: (a) high efficiency of light production when activated by radiation. (b) emission of light at a wavelength that is within the region of maximum sensitivity of the photomultiplier tube, (c) good solubility and stability under conditions imposed by the nature of the sample and the working temperature of the counter, (d) no concentration quenching, and (e) ready available and low cost.

Good scintillators are compounds containing conjugated aromatic rings combined in a linear fashion. Of the many ring-structures studied, oxazole and 1,3,4 oxadiazole have formed the basis of the most widely used scintillators.

Among the most widely used primary scintillators are, for example: p-Terphenyl (TP), 2,5 - Diphenyloxazole (PPO), 2 phenyl-5-(4-biphenyl) -1,3,4- oxadiazole (PBD) and 2-(4-t-Butylphenyl)-5-(4-biphenyl) -1,3,4-oxadiazole (Butyl-PBD).

The main function of the secondary scintillator is to absorb the emitted light of the primary scintillator and to re-emit it at a longer wavelength correspond to the maximal sersitivity of the photomultiplier tube. When present in high concentration, the secondary scintillator may compete with quenching agents in reducing the efficiency of the primary scintillator.

The four commonly used secondary scintillators are 1,4-bis-2-(5-phenyloxazolyl) benzene (POPOP), 1,4-Bis-2-(4-methyl-5-phenyloxazolyl) benzene (DMPOPOP), P-Bis (0-methylstyryl) benzene (bis-MSB) and 2-(4'-Biphenylyl)-6-phenylbenzoxazole (PBBO).

The requirements for a good solvent are as follows: (a) high solubility for the scintillator, (b) efficient energy transfer from the radioactive source, (c) transparency to the photons emitted by the scintillation, (d) ability to dissolve the radioactive sample with or without the aid of solubilizing agents, and (e) ability not to freeze at the working temparature of the counter.

For many years, toluene has remained solvent of the choice from the point of view of relatively efficient energy transfer, cost and availability. Other solvents are dioxane and hexafluorobenzene.

The interaction of the particle radiation in liquid scintillators is summarized by the following equations:

1. $S + E \longrightarrow S^* + en$
2. $S^* + S_1 \longrightarrow S + S_1^* + en_1$
3. $S_1^* + S_2 \longrightarrow S_1 + S_2^* + en_2$
4. $S_2^* \longrightarrow S_2 + h$ (light)

where S = Solvent, S^* = excited solvent

E = radiation energy

S_1 = primary scintillator, S_1^* = excited primary scintillator

S_2 = secondary scintillator, S_2^* = excited secondary scintillator

en, en_1, en_2 = energy releasing (heat)

And the sequence of the interaction involves:

1. the release of disintegration energy,
2. the transfer of energy to the solvent and then to the scintillator

3. fluorescence

2.2 Instrumentation of Liquid Scintillation Counter.

Photons which are generated in the scintillation process are collected and converted to measurable electrical pulses in a liquid scintillation counter. The important parts of the instrument include the photomultiplier tube, the amplifier, the pulse height analyzer and the scaler.

2.2.1 Photomultiplier tubes.

The photomultiplier is a vacuum tube which converts photons into electrical energy. It consists of a photocathode and a series of dynodes. The photocathode and the dynodes are coated with material that have the property of emitting photoelectrons when exposed to photons. The photoelectrons from the cathode are then accelerated by a positive potential into the first dynode. The impact of each accelerated photoelectron causes the production of several secondary electrons. The electrons produced at the first dynode are then accelerated toward a second dynode. This process is repeated through a series of dynodes until the secondary eletrons emerging at the last dynode reach the collector (anode) as an avalanch and result in a measurable electrical pulse. One photoelectron may generate as many as a million secondary electrons. The over-all electron multiplication can be controlled by changing the positive potential gradient applied to the tube. Again, this is a near-linear process, so proportional counting is possible.

Factors affecting the performance of photomultiplier tubes include:

(a) Spectral response

The photomultiplier tubes used for liquid scintillation counting must have a high sensitivity in the blue region of light because the liquid scintillators have blue emission. The spectral response of the photomultiplier depends on the composition of the photocathode. Photomultiplier tubes using bialkali cathodes, such as cesium-antimony, silver-magnesium-cesium, have been found to be particularly useful because of their excellent sensitivity in the blue region.

(b) Magnetic Fields

The performance of all photomultiplier tube may be influenced by the presence of a magnetic field because they generate photoelectrons that can be deflected by a magnetic field. In a liquid scintillation counter, care must be taken to shield the photomultiplier tube from external magnetic fields to ensure constant reproducible performance.

(c) Temperature effects.

A critical characteristic of photomultiplier tubes is the rapid increase of dark current with increasing temperatures as a result of increased thermionic emission of electrons from the photocathode. This expresses itself as an increase in background counts in a scintillation counter.

2.2.2 The two tube liquid scintillation counter.

In a single-tube liquid scintillation counter, the photoelectrons are multiplied by the photomultiplier tube to produce a measurable electrical pulse. The resultant pulse is subsequently amplified linearly by an amplifier to facilitate pulse height analysis.

The major drawback of the single-tube liquid scintillation counter is produced by the noise characteristics of the photomultiplier tube because the photocathode also emits electrons spontaneously (thermal electrons). Consequently, the spontaneous release of electrons would give in a high background count. It is evident that the high backtround count could be reduced to a tolerable level by cooling and by the use of two photomultiplier tube with a coincidence circuit.

A diagramatic representation of a liquid scintillation counter employing a coincidence circuit is shown in Figure 2.1

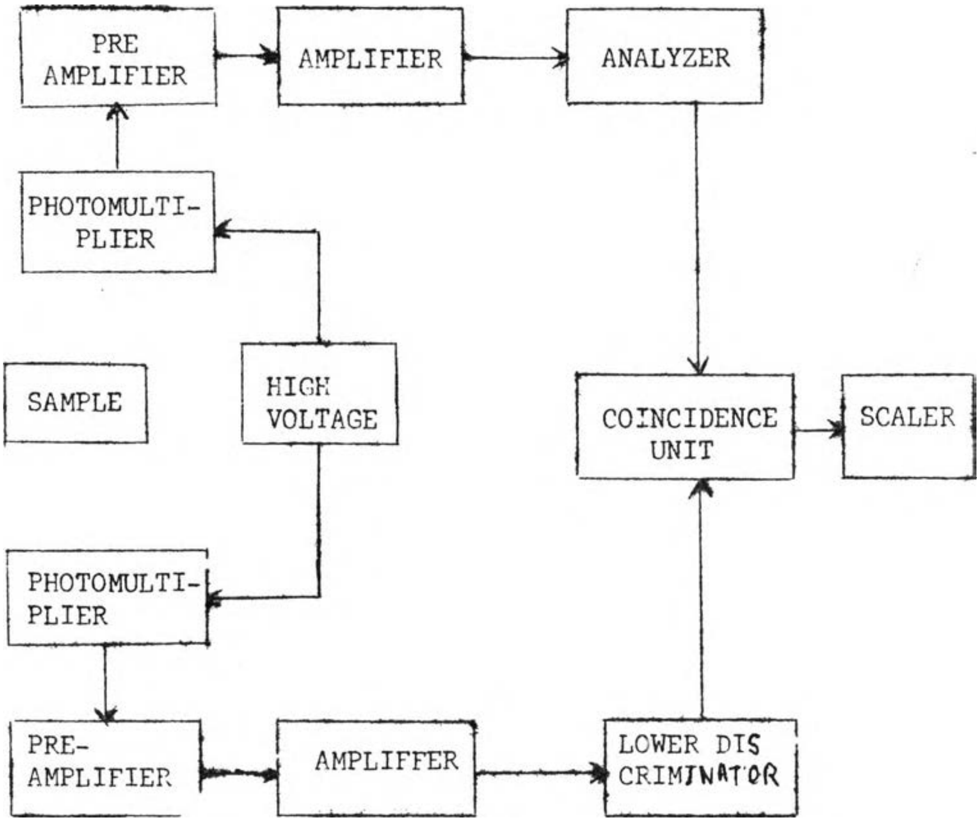

Figure 2.1 Block diagram of a two-photomultiplier tube liquid scintillation counter with a single analysis channel.

2.2.2.1 Pulse height analyser

The pulse height analyser is an electronic sorter that can be adjusted to accept electrical pulse within a selected range of pulse heights and reject all others. The principle of pulse height analysis is illustrated in Figure 2.2

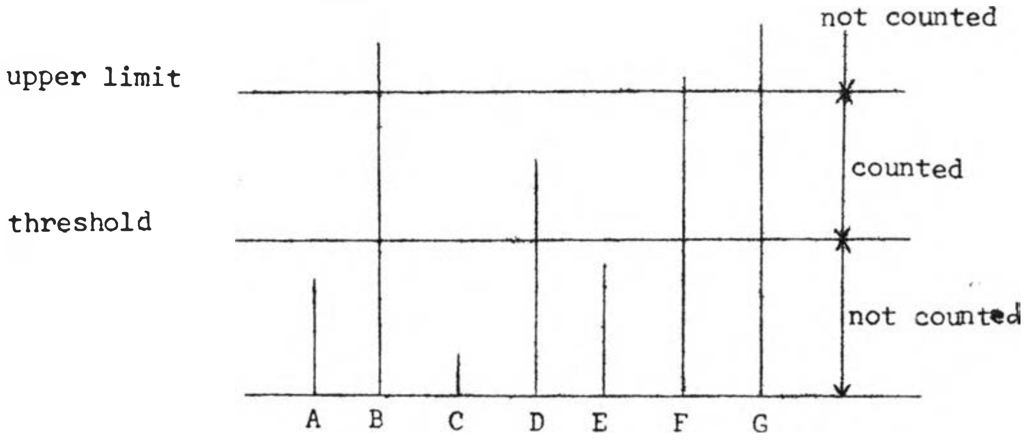

Figure 2.2 Principle of pulse height analysis.

The bars A through G represent seven pulses of varying energies generated by the photomultiplier tube, the energy being directly proportional to the height of the bars, which are subsequently analysed by a pulse height analyser. The pulse height analyser is set by means of two discriminators (lower and upper) that determine the size of the pulses to be passed or and reject all others. In this example, pulses A, C and E are rejected because they are too small and pulses B, F, G are rejected because they are too large. Only pulse D is pass on for further processing.

2.2.2.2 Coincident counting.

The two photomultiplier tubes, which are used in the two tube liquid scintillation counter, are specially selected for low-noise characteristics and matched for spectral response. These tubes are so arranged that they look at the same sample and are connected to a coincidence circuit. The coincidence circuit is an electronic device that only passes signals arising simultaneously from both photomultiplier tubes.

According to Figure 2.1, the second photomultiplier tube is used simply to monitor for coincidence. Therefore, any signal from the monitor tube is analysed only by a lower level discriminator so that all signals above the minimum level are passed on to the conicidence circuit. When the signal from the monitor tube arrives at the coincidence unit, an electronic gate is opened for a finite time, and any signal arriving from the analyser tube and to the pulse height analyser is allowed to pass on to the counter during this time. Because pulses originating from a radioactive source are seen simultaneously by both the monitor and the analyser photomultiplier tubes, these signals arrive simultaneously at the coincidence gate and are counted. In contrast, the random background pulses origination in the analyser tube do not pass the coincidence unit, even at very high background count rates.

2.3 Sources of Background Counts.

In a liquid scintillation counter, one of the sources of background is cosmic rays, which constitute the external source of background counts, Cosmic rays are high-energy particles that interact with matter to produce mesons, electrons, gamma rays and x-ray which, in turn, irradiate the counter from all directions. The counter is protected from cosmic rays by shielding with a high density material but it is not possible to eliminate the background counts completely.

Another major source of background counts is the naturally occurring radioisotopes contained in the materials used in the manufacture of the counter, the sample container, and the sample itself.

An obvious, though sometimes forgotten, source of background is the location of the counter near such high energy sources as gamma irradiators, neutron generators and similar instruments. A liquid scintillation counter should therefore be isolated from these installations.

The background count rate is always substracted from the sample count rate to obtain the net sample counts.

2.4 Figure of Merit.

In the field of liquid scintillation counting, the performance of a given counter is often expressed in term of figure of merit from which one could estimate the time needed to count a sample so that a statistically acceptable number of count could be obtained. The time required to achieve a statistically acceptable number is a function of the efficiency and of the background of the counter. The figure of merit is $E^2/_B$, where E is the efficiency and B is the background in counts per minute. The higher the figure of merit, the less counting time is required to achieve the statistical accuracy desired.

2.5 Quenching

The term "quenching", is applied to any factor that reduces the light output (photo production) in the system. Quenching can occur in several way, that is

(a) The sample itself may absorb light given off by the scintillator or some of its own radiation.

(b) The solvent may not transfer the energy of the radioactive particle efficiently to the scintillator.

(c) The scintillator itself may absorb some of its own fluorescence.

(d) Chemical interaction of the components contained in the counting solution may result in a reduced photon output.