The Influence of Chemical and Color Quenching on the Shape of Energy Spectrum for Beta Particles of $^{90}$Sr – $^{90}$Y by Using Liquid Scintillation Cocktail

M.W.M. Al-Badrani
Department of Physics, College of Education, Mosul University, Mosul, Iraq

Received 10 June 2008

Abstract. The effect of chemical quenching on the pulse height spectrum and $E_{\text{max}}$ of Strontium $^{90}\text{Sr}$ were studied using the organic scintillation cocktail and observing change in fluorescent yield and spectral shape (energy spectrum) of beta particles of $^{90}\text{Sr}$ isotope in determining a relationship between the magnitude of material that causes quenching and the position of energy spectrum and $E_{\text{max}}$, adding 3 M nitric acid (HNO$_3$) as chemical quencher to the scintillation, and added aqueous soluble yellow food dye with different concentration as color quencher. The beta detection efficiency depends on energy, spectral shape and cocktail. Typically, beta particles with maximum energies ($E_{\text{max}} > 0.250$ MeV) are detected with > 90% counting efficiency in organic liquid scintillation, where $^{90}\text{Sr}$ has maximum beta energy, $E_{\text{max}}$, of 0.546 MeV and half-life of 28.17 years. The results were compared with reference and literature values.

PACS number: 87.64.kv

1 Introduction

Modern spectrometers for radiation measurement using liquid scintillation cocktail technique are widely applied to beta emitting radionuclide determination, especially that of low energy radiation. Beta-particles are high energy electrons. These are produced during the $\beta$-decay. Beta-particles are emitted in concert with a neutrino (Neutrinos are almost impossible to detect). The sum of the energies of the neutrino and $\beta$-particle is a constant for a given isotope, and defines the maximum energy ($E_{\text{max}}$) which can be observed for any particle emitted from that isotope.

The liquid scintillation cocktail consists of a solvent and organic scintillators that convert the kinetic energy absorbed by $\beta$-particles into light flashes that
are detectable by the Photomultiplier of LS spectrometer, and the intensity of the light emission and energy of these $\beta$-particles are directly proportional to one another. The energy spectrum for beta emitting radio nuclides is different from alpha particles when detected in a liquid scintillation counter because beta emitters produce a continuous spectra from zero to the energy maximum ($E_{\text{max}}$) for the radionuclide [1]. The $\beta$-particle spectrum is continuous because the rest of the decay energy is transferred to the neutrino particle. The electronic cloud of the toluene ring (or any aromatic ring) provides a target for $\beta$-interaction, which absorbs the energy of the incident particle. This captured energy is generally lost through transfer to another solvent molecule, as toluene has little tendency to emit light or undergo other alternate decay modes. Thus, a $\beta$-particle passing through a toluene solution leaves in its wake a number of energized toluene molecules. The energy from these molecules passes back and forth among the solvent ring systems, allowing efficient capture by dissolved phosphors.

For $\beta$-particles (or positrons) in a LS cocktail, 10 photons of light are produced per keV of $\beta$ decay energy. This light then can be detected and quantified. The total light produced is the scintillation and its intensity depends on the energy of the $\beta$-particle emitted, as this influences the number of collisions the particle has with solvent molecules.

2 Chemical and Color Quenching

The number of counts recorded by a liquid scintillation counter is always less than the number of emissions by the sample. This is because the counter is not 100% efficient. Quenching is a major factor influencing counting efficiency, and quenching can be defined as any decrease in efficiency resulting from the sample or substances in the scintillation cocktail. In applications where the specific activity of a sample must be known, quenching or loss in efficiency must be determined and the data adjusted accordingly. There are two main types of quenching: chemical quenching occurs when chemicals in the cocktail absorb radiation from a radioactive emission event before it can be converted to light. Water can be a chemical quencher, organic compounds containing Oxygen (i.e. aldehydes and alcohols), or halogens (e.g. chloroform) and nitromethane are generally strong chemical quenchers [2]. Such samples should be counted in as dilute a solution as possible, to minimize the quenching effect. Color quenching is an attenuation of the photons of light. The photons produced are absorbed or scattered by the color in the solution and occur when colored solutions absorb light emitted at range 3500–4500 Å from the Phosphors, preventing its detection by the PM tubes. In general, samples which appear yellow or brown will be quenched to some extent and Red solutions tend to be fairly potent color quenchers. In both cases of quenching, total counts are reduced, and the ratio of high to low energy counts is decreased, the effect of increased quenching is to shift the beta spectral peak to a lower energy region, illustrates that the location
of the spectral peak (keV) is directly dependent on the beta energy and degree of quench for any beta emitter.

3 Materials and Methods

The experimental work was carried out by using a simple and effective detection system shown in Figure 1. This detection system included liquid scintillation vial, the beta source (Sr-90) centered on top of the source stand in the vial where the distance between source and surface of liquid scintillation is about 20 mm. The vial itself is attached to photomultiplier tube (Philips XP 1000) with quantum efficiency of 25% at 4000 Å wavelength [3]. The phototube is connected to H.V power supply module (pw 4620) and spectroscopy amplifier module 2021, timer, counter and CANBERRA Multi-Channel Analyzer (model 8503), where the pulses are collected and analyzed. Finally, the spectrum was processed and displayed on a computer.

A six polyethylene (HDPE) standard vials (20 ml) set are used to contain the liquid scintillator. polyethylene vials were compared with Glass vials that gave poor results both for background and spectral beta resolution; best results were obtained when using Teflon and polyethylene vials. Teflon vials were discarded because of their high cost, while polyethylene vials are permeable to cocktail solvent [4], which exhibit good resolution, low background and no solvent per-

---

Figure 1. Schematic diagram of experimental setup
meability. The sides and part of the bottom of the vial were covered with a thin layer of aluminum foil. The aluminum foil was placed around the sides of the vial to provide a reflective surface to collect any light produced.

The effect of quenching on scintillation yield by beta emitters of $^{90}\text{Sr}$ is revealed in Figures 2-7, where preparing six samples that have been quenched with range 0–2.0 ml of nitric acid mixed with 10 ml of scintillation cocktail contained toluene as solvent, 5 g/L PPO as primary solute, 0.5 g/L bis-MSB as wave shifter, and 40 g/L naphthalene are to increase the efficiency of the transfer of energy from the solvent to the solutes or to offer better beta spectra. After that another six samples contained the same scintillation cocktail above (hereinbefore) that have been color quenched with range 5–50 μl of aqueous soluble food yellow dye.

4 Discussion of the Results

It can be seen in Figures 2–7 the area under each peak or pulse-height spectrum as well as the energy for Strontium is reduced with an increase in nitric acid loading, where (Table 1) illustrates that the relative counting rate (number of light flashes) is decreased to 19.6% when 2.0 ml of 3 M nitric acid is added to the sample. This is the result of chemical quenching that absorbs some of the energy of $\beta$-particles before and during the conversion of the $\beta$-particles energy to fluorescent light. Figure 2 shows that there is another small peak, this peak is for $\beta$-particles of Yttrium-90 daughter of $^{90}\text{Sr}$.

<table>
<thead>
<tr>
<th>HNO₃ concentration in liquid scintillation cocktail [ml]</th>
<th>Count rate (intensity) [counts]</th>
<th>Peak position [Channel No.]</th>
<th>$E_{\text{max}}$ position [Channel No.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>144800</td>
<td>409</td>
<td>1944</td>
</tr>
<tr>
<td>0.1</td>
<td>113350</td>
<td>379</td>
<td>1818</td>
</tr>
<tr>
<td>0.5</td>
<td>86200</td>
<td>292</td>
<td>1650</td>
</tr>
<tr>
<td>1.0</td>
<td>59020</td>
<td>274</td>
<td>1439</td>
</tr>
<tr>
<td>1.5</td>
<td>46100</td>
<td>242</td>
<td>1294</td>
</tr>
<tr>
<td>2.0</td>
<td>28450</td>
<td>189</td>
<td>979</td>
</tr>
</tbody>
</table>

Figures 2–7 show also that the peaks are shifted to a lower energy (lower Channel number) and broadened as the amount of nitric acid is increased, where the peak position of beta spectrum is shifted from approximately Ch. 400 before acid added to Ch. 189 when 2.0 ml of 3 M nitric acid is added to the liquid scintillation cocktail (see Figure 7).

The quench is increased from vial to vial by the addition of a quenching acid, which causes a shift in the position of (the spectrum endpoint) $E_{\text{max}}$ stan-
Figure 2. Energy spectrum of $^{90}$Sr without quenching.

Figure 3. Quenching effect of 0.1 ml HNO$_3$.

Figure 4. Quenching effect of 0.5 ml HNO$_3$.

Figure 5. Quenching effect of 1.0 ml HNO$_3$.

Figure 6. Quenching effect of 1.5 ml HNO$_3$.

Figure 7. Quenching effect of 2.0 ml HNO$_3$. 
The Influence of Chemical and Color Quenching on the Energy Spectrum for...

dard continuous beta spectrum to a lower Channel number, where shifted from Ch. 1944 to Ch. 979, and a subsequent decrease in the counting efficiency of $^{90}$Sr radioactivity (see Table 1).

Table 2. Quenching effect of yellow food dye on the count rate, peak position, and $E_{\text{max}}$ position of $^{90}$Sr.

<table>
<thead>
<tr>
<th>Yellow food dye concentration in liquid scintillation cocktail [µl]</th>
<th>Count rate (intensity) [count/s]</th>
<th>Peak position [Channel No.]</th>
<th>$E_{\text{max}}$ [Channel No.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>144800</td>
<td>409</td>
<td>1944</td>
</tr>
<tr>
<td>5</td>
<td>107250</td>
<td>405</td>
<td>1875</td>
</tr>
<tr>
<td>10</td>
<td>88100</td>
<td>362</td>
<td>1684</td>
</tr>
<tr>
<td>20</td>
<td>69420</td>
<td>289</td>
<td>1579</td>
</tr>
<tr>
<td>30</td>
<td>48100</td>
<td>279</td>
<td>1516</td>
</tr>
<tr>
<td>40</td>
<td>29420</td>
<td>235</td>
<td>1245</td>
</tr>
<tr>
<td>50</td>
<td>19800</td>
<td>192</td>
<td>934</td>
</tr>
</tbody>
</table>

The cause of naphthalene added to the scintillation cocktail is to reduce (internal conversion) the non-radiation process and enhance the counting efficiency, because naphthalene has little Stokes loss [5]. The reduced beta photon yield or fluorescence quenching may occur because of existing little amount of Oxygen, where was found [6] that the effect of Oxygen quenching on the first excited singlet state of a molecule leads to reduction in its photon yield and values of $L_0/L$ (where $L_0$ is the fluorescence intensity of a scintillation solution in the absence of air and $L$ is the fluorescence intensity of the same solution with air). The value of ratio $L_0/L$ for ingredients of scintillation cocktail: toluene = 3.0, PPO = 1.1, bis-MSB = 1.08, g/L naphthalene = 6.4 [6], so the effect of Oxygen on PPO and bis-MSB is negligible, whereas has hard effect on both naphthalene and toluene, in general the Oxygen has paramagnetic properties, therefore it will increase the inter system crossing between the first singlet excited state (S1) and first triplet excited state (T1) and which causes a decrease in the counting efficiency of the liquid scintillation cocktail [7]. The light output (Intensity) and end point energy $E_{\text{max}}$ are important parameters of the influence of nitric acid on beta spectroscopy by using liquid scintillation system. Figures 2–7 show intrinsic reduction of the light intensity and Ch. number of $E_{\text{max}}$ and the pulse-height (energy) of the peak with increasing volumes of nitric acid added. With no acid added to the cocktail, the value of intensity is 144800 C/s and the Ch. number of $E_{\text{max}}$ is about 1944. However, with increasing volumes of 3 M nitric acid to 2.0 ml, the values above degrade to 19.6% and 50.3%. The path of a $\beta$-particle in a scintillation cocktail is generally less than 0.1 cm; and the half life is correspondingly. Therefore, chemical quenchers reduce the number of photons generated by each $\beta$-particle.

Figures 8–13 show that the photo peaks are shifted also to a lower energy (lower Channel number) with the increase of yellow food dye added, where the peak po-
Figure 8. Quenching effect of 5 µl yellow food dye.

Figure 9. Quenching effect of 10 µl yellow food dye.

Figure 10. Quenching effect of 20 µl yellow food dye.

Figure 11. Quenching effect of 30 µl yellow food dye.

Figure 12. Quenching effect of 40 µl yellow food dye.

Figure 13. Quenching effect of 50 µl yellow food dye.
The Influence of Chemical and Color Quenching on the Energy Spectrum for...

sition of beta spectrum is shifted from approximately Ch. 409 before dye added to Ch. 192 when 50 \( \mu \)l of yellow food dye is added to the liquid scintillation cocktail (see Figure 13).

Figures 8–13 show a constitutive spectral distortions in the strontium energy spectrum and reduction in count rate for Strontium with an increase in yellow food dye loading, where (Table 2) illustrates that the relative counting rate is decreased to 13.6% when 50 \( \mu \)l of yellow dye is added to the Liquid scintillation cocktail, while the spectrum endpoint \( E_{\text{max}} \) was approximately unchanged even when 50 \( \mu \)l dye is added to the liquid scintillation vial, and these results were in agreement with [8].

5 Conclusion

The results presented in this paper show that a liquid scintillation spectrometer technique is most successful to measure \( \beta \)-particles intensity and illustrate the pulse shape discriminating for \( ^{90}\text{Sr} \) and \( ^{90}\text{Y} \). The main disadvantage is its higher detection limit for determination of \( ^{90}\text{Sr} \) by liquid scintillation counting due to the high background of the counter and this result is in agreement with [9]. the effect of increased chemical quenching by (nitric acid) is to shift the beta spectral peak and \( E_{\text{max}} \) to a lower energy region (lower channels). And the location of beta spectral peak directly dependent on the beta energy and amount of HNO\(_3\) added. The results indicate that colored dye may decrease the amount of light that can reach the PMT thus decreasing its detection, which causes a shift in the standard spectrum to a lower energy and a subsequent decrease in the counting efficiency of the radioactive standard. The liquid scintillation cocktail provides acceptable energy resolution which decreases with addition of the quencher acid in the liquid scintillation. The results of this work are compared with those from Pujol’s work [10] and show that the Quenching agent addition to scintillator vial has more distinct influence on small cocktail volume, but this relationship is not linear.

Finally, the present results indicate that in the presence of chemical or color quenching, the sample spectrum shifts to lower apparent energies, as fewer photons are produced or those that are produced are absorbed in the colored sample. It is also independent of the absolute color of a colored compound, since spectral distortions caused by differences in absolute color do not affect the spectrum endpoint.

References


149
M.W.M Al-Badrani


