

SHORT COMMUNICATION

Colour Quenching in Liquid Scintillation Coincidence Counters

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I should like to point out an interesting aspect of the quenching model I put forward two years ago.¹ Briefly, its essential features were as follows. In this highly simplified model the three-dimensional sample is replaced by a one-dimensional one, i.e. by the line joining the photocathodes of the photomultiplier tubes (see Fig. 1). In the absence of optical quenching the pulse height at the output of each

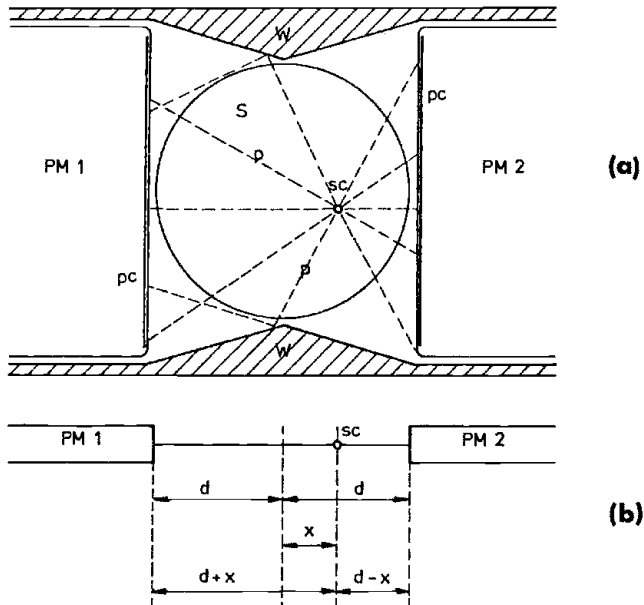


Fig. 1. (a) Schematic cross-section through liquid scintillation detector chamber with photomultipliers (PM) and their photocathodes (pc), reflective chamber walls (W), sample (S), arbitrary scintillation event (sc) and photon paths (p). (b) Simplified one-dimensional representation as discussed in text.

photomultiplier, as a result of an arbitrary scintillation event (sc), is represented by:

$$h_1(E) = h_2(E) = \frac{1}{2} qcE \quad (1)$$

where E is the energy of the β -particle, c is the conversion factor for an unquenched sample and q represents the pulse height reduction factor due to chemical quenching.

In the presence of colour quenching there is an additional attenuation of the pulse due to light absorption, which depends on the photon path length. Consequently, the pulse heights at the output of the photomultipliers will now generally be different. If the one-dimensional 'sample' has a 'diameter' $2d$, the distance of the scintillation event to the centre of the 'sample' is x , and the optical attenuation constant is μ , we find:

$$h_1(E, x) = \frac{1}{2} \exp[-\mu(d+x)] [qcE] \quad (1a)$$

and:

$$h_2(E, x) = \frac{1}{2} \exp[-\mu(d-x)] [qcE] \quad (1b)$$

In coincidence counters these two pulses are usually added linearly in a pulse summation circuit prior to analysis. The pulse height at the output of this circuit is then given by:

$$h_s(E, x) = h_1 + h_2 = \frac{\exp[-\mu(d+x)] + \exp[-\mu(d-x)]}{2} [qcE]$$

This can also be written as:

$$h_s(E, x) = \cosh(\mu x) [\exp(-\mu d)qcE] \quad (2)$$

Equation (2) shows that, unless $\mu = 0$, the pulse height for a given energy E depends on the position x of the scintillation event in the sample. From this we may conclude that chemically quenched samples and optically quenched samples must produce differently shaped pulse height spectra in coincidence counters provided with linear summation.

However — and now I come to the point I want to make — if a logarithmic summation is applied we obtain a different picture:

Taking the logarithms of expressions (1a) and (1b) and adding yields the following answer:

$$\begin{aligned} \log h_1(E, x) &= -\mu d - \mu x + \log\left(\frac{1}{2} qcE\right) \\ \log h_2(E, x) &= -\mu d + \mu x + \log\left(\frac{1}{2} qcE\right) \\ + & \frac{\log h_1 + \log h_2}{\log h_1 + \log h_2} = -2\mu d + 2 \log\left(\frac{1}{2} qcE\right) \end{aligned} \quad (3)$$

We see that the term containing x is cancelled out.

If the model were sufficiently representative of the actual conditions in a liquid scintillation counter, it would mean that, by summing the logarithms of the signals from both photomultipliers, we would obtain an instrument with a similar response to both chemically and optically quenched samples.

Unfortunately the model is too primitive for this purpose, but we may hope that considerations of this nature will prove useful when a more sophisticated model becomes available.

The objection has been made that logarithmic addition is, in fact, equivalent to a multiplication of the photomultiplier signals and that this is very far from producing a useful signal for analysis. I am inclined to disagree with this and

prefer to look upon logarithmic summation as a way of obtaining the geometric mean of the individual photomultiplier pulses as opposed to the arithmetic mean that is obtained by linear summation.

Equation (3) can be transformed as follows:

$$\begin{aligned}\frac{1}{2}(\log h_1 + \log h_2) &= -\mu d + \log\left(\frac{1}{2}qcE\right) \\ \log(h_1 h_2)^{\frac{1}{2}} &= -\mu d + \log\left(\frac{1}{2}qcE\right) \\ \sqrt{h_1 h_2} &= \exp(-\mu d) \left(\frac{1}{2}qcE\right)\end{aligned}\tag{4}$$

This indicates that, according to the model, the geometric mean of the individual photomultiplier pulses is proportional to E and independent of the position of the scintillation event in the sample.

The similarity in the response of the model to chemical and optical quenching, if logarithmic summation is applied, is even more striking if we replace q by the approximation:

$$q = \exp(-k\gamma)$$

where γ is the chemical quencher concentration and k is a constant of proportionality.

Equation (4) then becomes:

$$\sqrt{h_1 h_2} = \frac{1}{2} \exp(-\mu d - k\gamma) [cE]$$

REFERENCE

- 1 F.E.L. ten Haaf, in Liquid Scintillation Counting (Eds. M.A. Crook, P. Johnson and B. Scales), Heyden, London, 1972, Volume 2, p.39.