CHARACTERISTICS OF PLASTIC SCINTILLATOR GRANULES

Yu. A. Tsirln, V. A. Shvets, A. Ya. Berlovskii, and V. M. Solomonov


Methods are described for measuring the absorption coefficient of the material, the absorption coefficient of a layer of granules, and the scintillation performance. The theory of light diffusion in a scattering medium is used and is compared with experiment.

Granulated plastic scintillator is used for internal counting of radioactive liquids, especially aqueous solutions of β-emitters [1, 2], the solution being poured into a flat-bottomed vessel containing a layer with p g/cm² of granules. The vessel is placed on a photomultiplier, with the scalar operated with a simple discriminator. The most important characteristics are the efficiency E (count/disintegration) and the counting volume v (ml/cm²), i.e., the volume that can be used with a specified counting efficiency.

Tests have shown that standard equipment used with a FEU-19 photomultiplier and granules with r ≈ 170 μm will give an efficiency for C¹⁴ of about 35% even in amounts as small as 0.1 μM [3].

The scintillation light is absorbed by the layer, so the effective absorption may be characterized by a factor x, which tends to a limit as the thickness increases; E at the same time decreases.

<table>
<thead>
<tr>
<th>Medium</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = n₀/n₁</td>
<td>1</td>
<td>1.33</td>
<td>1.50</td>
</tr>
<tr>
<td>I' (μA · cm² · g⁻¹)</td>
<td>0.48</td>
<td>0.70</td>
<td>0.90</td>
</tr>
<tr>
<td>I₀ (μA)</td>
<td>0.085</td>
<td>1.135</td>
<td>0.23</td>
</tr>
<tr>
<td>x (cm⁻¹ · g⁻¹)</td>
<td>6.2</td>
<td>5.8</td>
<td>3.9</td>
</tr>
</tbody>
</table>

The v for a given β emitter and discriminator setting increases with the scintillation efficiency η of the granules and the technical light yield τη, while it is inversely related to x.

E should increase as r is reduced (due to reduction in self-absorption in the liquid), as is found with thin layers (with little light absorption); the fall in E as p increases is the more rapid the greater r (as will be shown below) the smaller r.

The theory of such detectors has been discussed [4], and it has been shown that E is governed by r, x, and η for a given radiation source and given discriminator threshold. Granule testing must therefore include measurement of η and x for the r appropriate to the problem. The arguments given here are for this case, the directly measured quantity being the photocurrent I, which is proportional to the light flux F at the cathode.
Theory. The transmission of light through the layer to the cathode is a diffusion process, each particle being a center characterized by scattering and absorption cross sections \( \sigma_s \) and \( \sigma_a \). The corresponding quantities of 1 g of granules and \( \Sigma_s \) and \( \Sigma_a \).

The transmission coefficient \( \tau \) for light falling from outside onto the layer of granules is given by theory [4] as

\[
\tau = \frac{F}{F_0} = \frac{I}{I_0} = \frac{1}{\text{ch} \times p + \gamma \text{sh} \times p},
\]

\[
\kappa = \sqrt{3\Sigma_a \Sigma_s (1 - \mu)},
\]

\[
\gamma = \frac{(1 - r_1)(1 - r_2)}{2a (1 - r_1 r_2)},
\]

\[
\alpha = \sqrt{\frac{4\sigma_a}{3\sigma_s (1 - \mu)}}.
\]

Here \( \mu \) is the mean cosine of the scattering angle produced by a particle, \( r_1 \) and \( r_2 \) are the reflection coefficients at the upper and lower boundaries of the layer, \( F \) and \( I \) are the light flux and current for a layer \( p \), and \( F_0 \) and \( I_0 \) are the same for \( p = 0 \).

It can be shown that for spherical particles with \( n = 1.5 \) and diameter \( d \)

\[
\kappa = 1.67d^{-1/2} k^{1/2},
\]

in which \( k \) is the absorption coefficient of the material. If \( kp \gg 1 \),

\[
\ln \tau \approx \ln \frac{1 + \gamma}{2} - \kappa \cdot p.
\]

To deduce the \( F \) due to a scintillation at a distance \( x \) from the photocathode we have to include the following factors,

\[
F = \eta f \frac{\beta}{\kappa} \frac{\text{sh} \times p}{\kappa \text{sh} \times p + \beta \text{ch} \times p},
\]

in which

\[
\beta = \frac{3}{2} \Sigma_s (1 - \mu).
\]

\( F \) is given by the following asymptotic formulas when \( r_1 \neq 1, r_2 = 0 \):

\[
F = \eta t r_1 (\kappa \cdot p \ll 1), \quad F' (0) = \eta t r_1,
\]

\[
\lim_{xp \to \infty} F = F_0 = \eta t \kappa.
\]

The problem is to determine \( \eta \) and \( \kappa \) for grains of a given \( r \).

Experimental. Standard plastic scintillator (PS), 2% terphenyl + 0.15% POPOP in polystyrene, was used. The first tests were done on grains from polymerization 1 (0.1-0.25 \( \mu \)m fraction), \( I(p) \) being recorded with the \( \gamma \)-rays of Co\(^{60}\) as a function of immersion medium (air, water, paraffin oil) with the layer of granules covered with PTFE (\( r_1 = 0.9 \)). Figure 2 shows the results as the measured current \( I_1 \) corrected for the dark current \( I_d \). The parameters \( I'(0) \) (derivative at the origin) and \( I_0 \) (saturation current) were deduced, \( \kappa \) being found from (9) and (10). The results are given in Table 1.

As \( F' \) is proportional to \( t \), the results for \( F' \) may be compared with Fig. 1 by bringing the points for \( n = 1.07 \) into coincidence (points in Fig. 1). Also, \( \eta \) was deduced as follows. The layer of granules was replaced by a plate of \( p \) g/cm\(^2\) of PS of the same composition, in the same vessel; the photocurrent \( I_s \) was measured. Then

\[
\eta = \frac{\eta_s}{\eta_s} = \frac{I'(0) p_1 t \Sigma_s}{t I'_s}.
\]