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The Detection of Alpha Rays by Single Crystals of Thallium Activated Sodium Iodide

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§ 1. Introduction.

The work described below has been carried out in an attempt to find phosphors for scintillation-counting which respond efficiently to alpha-rays or heavier particles and which are available in large transparent crystals.

Neither the widely used organic materials nor the various activated zinc sulphides fulfill both these conditions. Broser and Kallmann[1]) first pointed out that in the former the light production per unit energy loss in the crystal is much more efficient for electrons than for heavy particles. The zinc sulphides, on the other hand, are almost opaque to their fluorescent radiations[2]), whence the practical light yield falls of very rapidly with grain size. It appears, moreover, that artificially activated zinc sulphides are difficult to obtain in grains larger than a tenth of a millimetre.

Other inorganic materials such as cadmium sulphide, Scheelite, or the activated alkali halides suggest themselves, and a few results obtained with single crystals of thallium activated sodium iodide will here be reported.

Hofstaedter[3])[4]), stated that sodium iodide powder containing one percent thallium iodide appeared to respond to alpha rays with great efficiency, but that its usefulness was limited by the extreme hygroscopicity of the substance. We have attempted to find conditions in which this phosphor yields reliable results and to compare its response with that of silver activated zinc sulphide.

§ 2. Experimental Details.

For the purpose of the investigation single crystals of sodium iodide activated with one percent thallium iodide were used. These were grown by Dr. Ehrenberg and Mr. Franks of this College by a method which they have recently developed[5])[6]). The crystals were cleaved to obtain specimens of one to two millimetres thickness, which were then bombarded with alpha-rays from a polonium source giving about a thousand disintegrations per second.

Source and crystal were enclosed in a tubular holder through which a slow stream of air was passed containing water vapour at the vapour pressure of a saturated solution of sodium iodide in water. This was achieved by allowing air previously dried to pass over such a solution and then filtering it through a bed of sodium iodide powder. By this means condensation of water on the crystal as well as excessive drying-out were avoided. The crystals were attached to a window at one end of the holder; a micrometer screw carrying the source was mounted at the other end.

The silver activated zinc sulfide used for comparison was powder No. 256 manufactured by the Brimsdown Chemical Company, Brimsdown, Middlesex, which was mounted in form of a small screen in place of the sodium iodide scintillator.

The scintillations were recorded by means of a Mazda 27M1 nine-stage photo-multiplier followed by an amplifier giving a gain of 2000 and by discriminating, pulse-shaping and scaling units. The photo-cathode potential of — 1000 volts was provided by a stabilized Power Supply Unit, Type 1007.

In the experiments the crystals were allowed to attain equilibrium with their surroundings, indicated by a constant counting rate for given source distance and discriminator bias. Counts were then taken for various distances of the source from the phosphor and for a series of discriminator-settings in each case. After each count the source was removed, and a background count was taken. The source was then brought to a standard distance and with standard amplifier and discriminator-settings a fixed number of counts were timed to provide a check of the stability of the entire recording system.

§ 3. Results.

Let $N(v)$ represent the counting rate for pulses exceeding v volts after subtraction of the background rate. The variation of $N(v)$ with v for various alpha-ray energies is illustrated by the integral bias curves shown in figures 1 and 2 for sodium iodide and zinc sulphide respectively.

From the results indicated we have calculated the mean size of the output pulse by the formula

$$\bar{v} = \frac{\int_0^\infty N(v)\,dv}{N(o)}$$

where $N(o)$ is the total number of counts of all sizes. We have also estimated the standard deviation of the mean using the expression

$$\sigma_m = \frac{\sqrt{\left(\frac{\Sigma N(v_i)\,\sigma_0}{N(o)}\right)^2 + \Sigma \sigma_i^2}}{N(o)}\,\Delta V$$

where the $N_1(v_i)$ are the individual integral counting rates, σ_i the standard deviations of $N_1(v_i)$ and ΔV the equal intervals between the values of discriminator bias at which counts were taken.

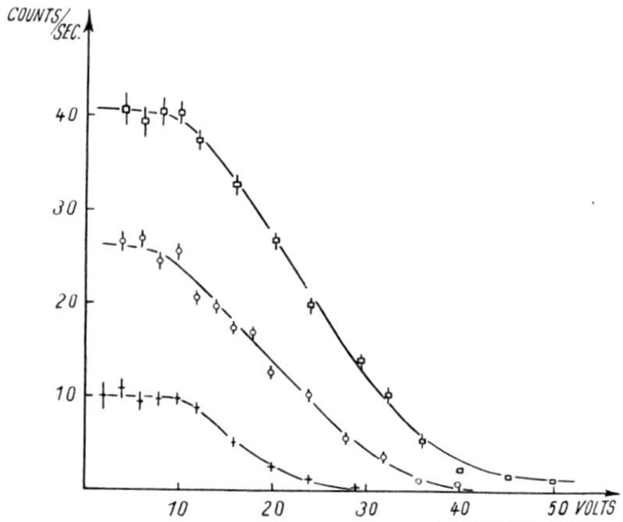

Fig. 1.

Sodium iodide Activator: 1% Tl

□ Source at 0.85 cms ○ Source at 1.35 cms + Source at 1.85 cms

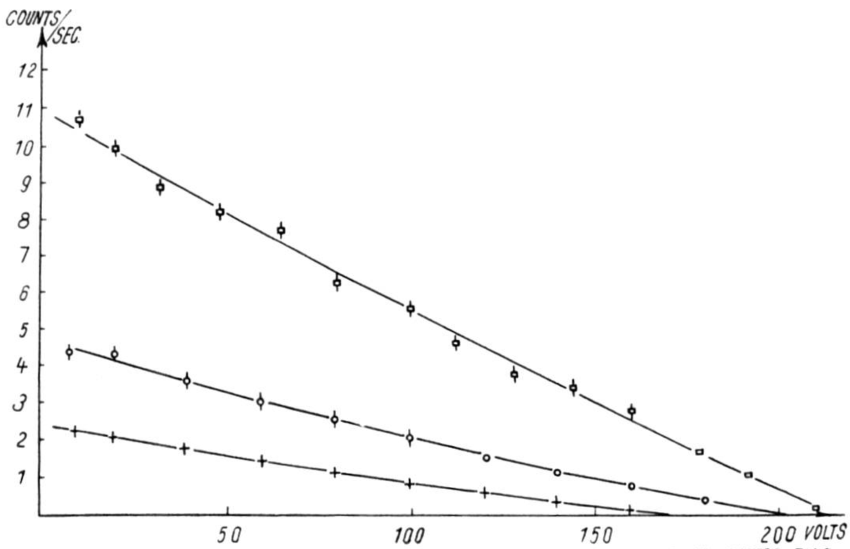

Fig. 2.

Zinc Sulfide Activator: Ag

□ Source at 0.85 cms ○ Source at 1.35 cms + Source at 1.85 cms

The calculated values of $\bar{v}$ and σ_m are shown in table I together with the fraction E/E_0 of the alpha-ray energy $E_0 = 5.4$ MeV absorbed in the phosphor.

Table I.

E/E_0	Mean Pulse Size $\bar{v}$ NaI	Mean Pulse Size $\bar{v}$ ZnS
0.575	15.8 ± 0.9	89.1 ± 3.2
0.695	18.8 ± 0.5	105.8 ± 3.5
0.825	23.5 ± 0.6	116.9 ± 1.8

The results are shown graphically in Fig. 3.

§ 4. Discussion.

The pulse size distribution is obtained from $N(v)$ by differentiation. This yields for zinc sulphide the approximately uniform distribution often associated with micro-crystalline phosphors and for sodium iodide an approximately Gaussian distribution characteristic for single crystal scintillators and similar to those found for other materials by Broser and Kallmann[7]), Garlick and Fatehally[8]) and Harding, Flowers and Epstein[9]).

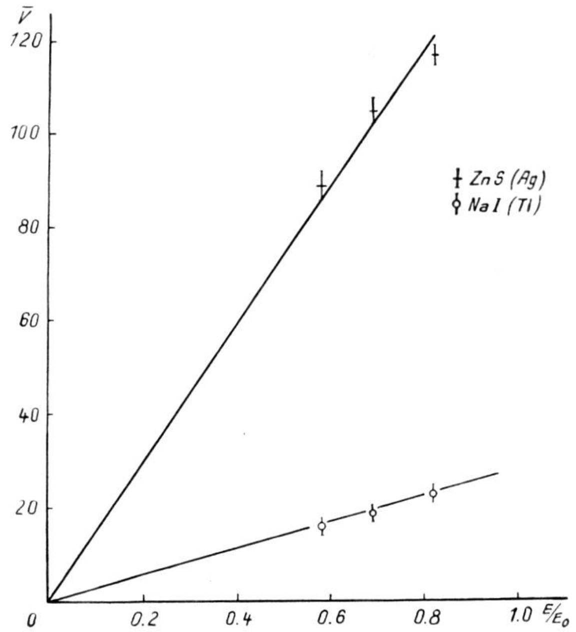

Fig. 3.
Mean Pulse Size as function of alpha-ray energy.

The reasons for the spread in pulse size have been discussed by Hoyt[10]). It is thought major causes of the wide spread in the case of the sodium iodide scintillators may have been the finite size of the alpha-ray source and certain imperfections in the crystal specimens, resulting in a considerable fluctuation of the number of photons arriving at the photo-cathode.

Fig. 3 indicates that the response is a linear function of the energy for both phosphors.

The values of the mean pulse size $\bar{v}$ for a given alpha-ray energy enable us to compare directly the efficiencies of the two phosphors when used in conjunction with a 27M1 photo-multiplier. Let this efficiency be η_1 for sodium iodide and η_2 for zinc sulphide. Then we have for excitation by alpha-rays

$$\frac{\eta_1}{\eta_2} = 0.19$$

The centre of the band of light emitted by thallium activated sodium iodide is quoted as 4100 A.U. by MILTON and HOFSTAEDTER[11]), the corresponding value for silver activated zinc sulphide is, according to KALLMANN[12]), 4500 A.U. In view of the variation with wavelength of the sensitivity of the photo-multiplier we arrive at a corrected ratio of 0.23 for the intensities of the recorded light flashes.

Accepting KALLMANN's value of 28% for the efficiency of light production by silver activated zinc sulphide under alpha-ray bombardment[12])[13]) we find a figure of about 6% for sodium iodide. This value does not confirm HOFSTAEDTER's estimate[3]), according to which the alpha-ray response of sodium iodide is about the same as that of zinc sulphide. Comparison with the data for other phosphors given by KALLMANN[12]) shows nevertheless that the material under investigation is a more efficient phosphor for alpha-ray counting than any of the substances listed except the zinc and cadmium sulphides. It may further be concluded that thallium activated sodium iodide is capable of yielding reproducible results if suitable precautions are taken.

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