SOME SCINTILLATION PROPERTIES OF UNACTIVATED CsI AT ROOM TEMPERATURE

R. Langkau

I Institute for Experimental Physics, Hamburg, Germany

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The scintillation behaviour as a function of time of an unactivated CsI crystal at room temperature has been investigated by means of a sampling storage process. Alpha particles and γ quanta were used to produce scintillation. The process is composed of a fast and a slow component, the intensity ratio of the two components depending to a very considerable extent on the type of the exciting radiation. This fact may be used to discriminate between particles.

* * *

The scintillation behaviour of unactivated CsI crystals has already been investigated[1-10] by many researchers, especially in conjunction with the temperature of the crystals. Most of their measurements, however, were made at temperature ranges below room temperature. It is hardly possible to compare the individual measurements qualitatively, since the scintillation properties clearly depend very much on the degree of purity of the raw material and on the method used to produce the crystal. Comparatively few data exist for room temperature, since precise measurement is made considerably more difficult here by the poor light yield of unactivated CsI.

This article describes how the scintillation properties at room temperature of an unactivated CsI crystal drawn from the melt* were investigated with the aid of an assembly which can also be used at very low light yields; a possible application is likewise discussed.

1. Measurement of the output pulses of the scintillation counter

a) Measuring assembly

The output pulse shapes of the counter (CsI crystal and 56 AVP photomultiplier) were measured with a sampling oscillograph (Tektronix, type 661), in which the pulse heights associated with the

* The crystal was drawn by Messrs. K. Korth of Kiel.

successive scanning times were suitably stored with the aid of a multi-channel pulse height analyser (RIDL, model 34-12)[11-13]. This method makes it possible to add the results measured for any given number of individual pulses, and thus to average out any statistical background noise superimposed on the pulse (considerable background noise may, for instance, occur when the light yield of the scintillator is low). Fig. 1 shows the layout of the measuring equipment.

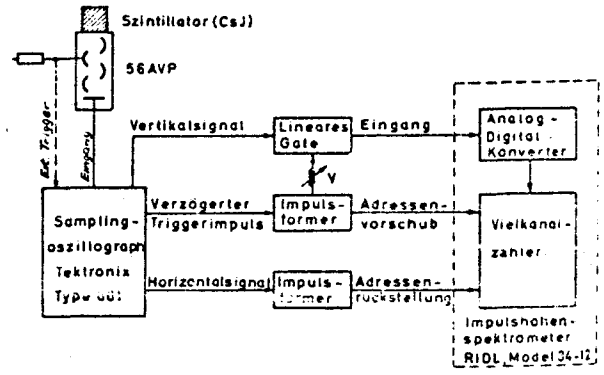

Fig. 1: Block circuit diagram of the pulse shape measuring equipment
Legend:
Szintillator (CsJ) = scintillator (CsI); Ext. Trigger = external trigger; Eingang = input; Vertikalsignal = vertical signal; lineares Gate = linear gate; Analog-Digital-Konverter = analog-digital converter; Verzögerter Triggerimpuls = delayed trigger pulse; Impulsformer = pulse shaper; Adressenvorschub = address advance; Vielkanalzähler = multi-channel counter; Sampling-Oszillograph Tektronix Type 661 = Tektronix type 661 sampling oscillograph; Horizontalsignal = horizontal signal; Adressenrückstellung = address reset; Impulshöhenspektrometer RIDL Model 34-12 = RIDL model 34-12 pulse height spectrometer.

The signal used for the vertical deflection of the cathode beam in the sampling oscillograph is a stepped voltage, the total height of the individual steps being proportional to the height of the pulse to be measured at the moment of scanning. This vertical signal is taken to a linear gate which is opened once per step for a fraction of the step duration.

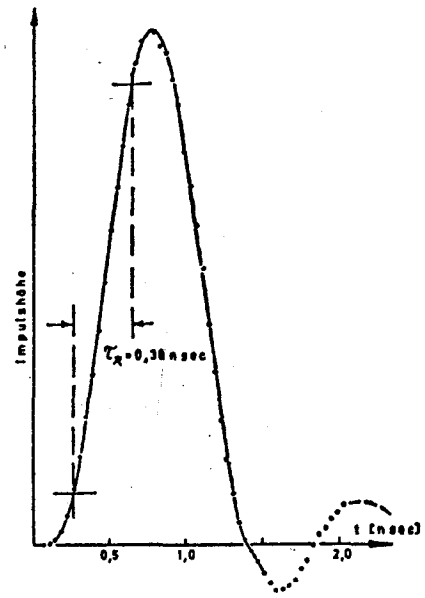

Fig. 2: Finding the time resolution. (Impulshöhe = pulse height)

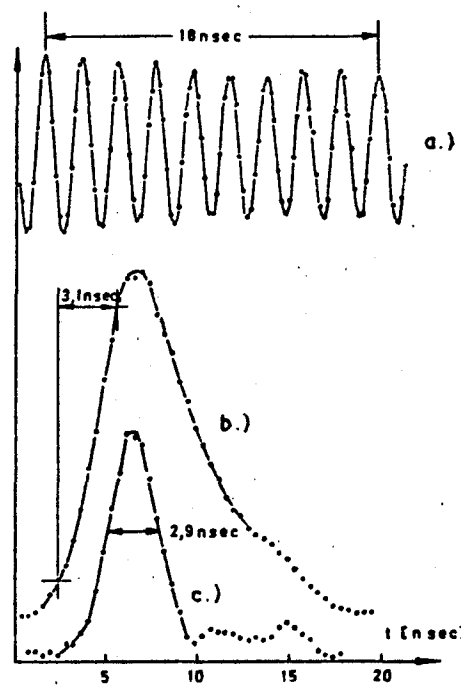

Fig. 3: Testing the equipment.

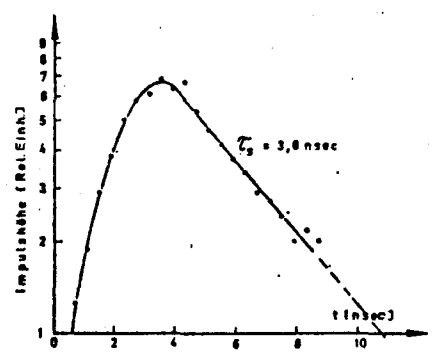

Fig. 4: Fast pulse component. (CsI crystal: alpha particle irradiation) (Rel. Einh. = relative units)

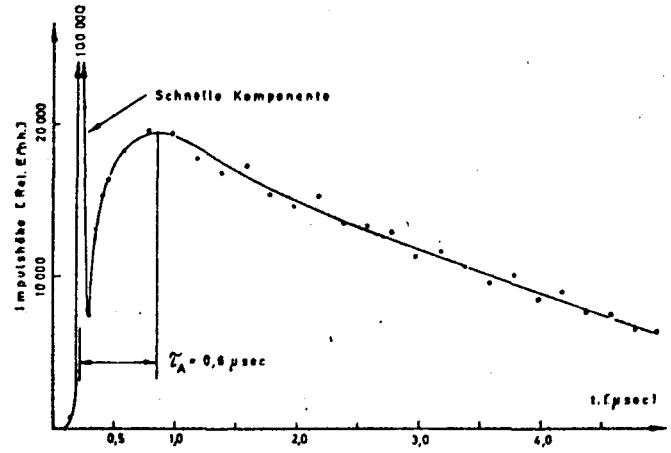

Fig. 5: Slow pulse component (CsI crystal: γ- quanta irradiation) (Schnelle Komponente = fast component)

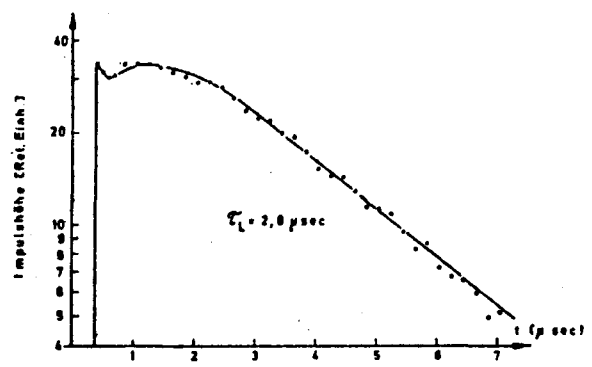

Fig. 6: Slow pulse component (CsI crystal: γ- quanta irradiation).

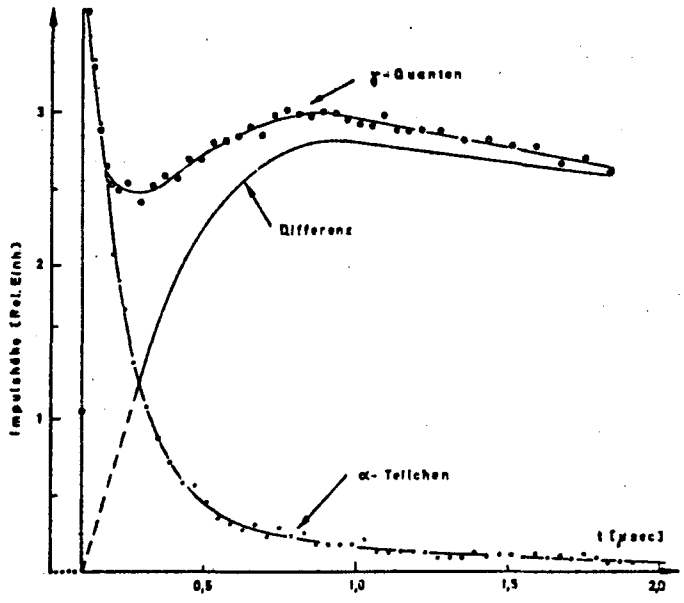

Fig. 7: Output pulses during irradiation with alpha particles and quanta (CsI crystal; R_A = 12 kohm). (γ-Quanten = quanta; Differenz = difference; α-Teilchen = alpha particles).

The square-wave pulses thus provided at the gate output pass to the input of the analog-digital converter in the multi-channel. The digitised pulse height information is then sent to the storage section of the multi-channel which acts as a multi-channel counter. The necessary correlation between the moment of scanning and the correct channel address is provided in the following way: Whenever the moment of scanning is advanced by one unit, the sampling oscillograph produces a square-wave pulse of constant shape (the delayed trigger pulse), which, after being suitably reshaped, is used as an address advance pulse. After the time for which the oscillograph is set has passed, the address is reset by means of a signal suitably derived from the trailing edge of the horizontal signal by a further pulse shaper. The delayed trigger pulse is also used to control the linear gate. Here, the delay V in the gate opening pulse ensures that the vertical signal is not passed to the analog-digital converter until the address has been set.

b) Testing the equipment

The electronic time resolution of the entire measuring assembly is determined by that of the sampling oscillograph. In order to test it, a generator (Tektronix, type 110) was used to supply brief "needle pulses" to the oscillograph input. Fig. 2 shows the result of the measurement. The observed rise time of 0.38 nsec is composed of that of the oscillograph (~0.35 nsec) and that of the test pulse.

Sinusoidal oscillations of known frequency were used to calibrate the time axis. A 500 MHZ oscillation recorded with the equipment is shown in Fig. 3a as an example.

The calibrating oscillations were produced by exciting LC resonant circuits with short square-wave pulses. This method is responsible for the amplitude fluctuations observed in Fig. 3a. Fig. 3 also shows the shapes of a scintillation pulse (plastic scintillator; curve b) and a noise pulse (single electron pulse) measured at the anode of the 56 AVP photomultiplier. The rise time

of the scintillation pulse and the width of the noise pulse give an idea of the magnitude of the transit time jitter and of the photomultiplier's own rise time.

The fluctuations superimposed on the late pulse curve, which are particularly marked at low pulse currents, are essentially a result of the less than ideal matching of the multiplier anode to the 50 ohm cable leading to the oscillograph. However, ideal matching is virtually impossible with the photomultiplier used here.

c) Results of measurement

Po^{210} alpha particles and Co^{60}-γ-quanta were used to excite the CsI crystal (dimensions: 20 mm high x 20 mm in diameter) to scintillation. The pulse shapes observed at the photomultiplier anode at a working resistance R_A = 50 ohm can be clearly divided into two components, one fast and one slow. The fast component shows an exponential decrease with a time constant τ_s = 3.6 nsec (see Fig. 4). Within the limits of the measuring accuracy, τ_s is independent of the type of radiation used (alpha particles of γ-quanta). An extrapolation to room temperature of the results of measurements by Rehmann et al.[1] and Lenz et al.[5] shows that τ_s can be expected to amount to a few nsec. In the case of the crystal examined here, the slow component of the pulse occurs at a measurable intensity only on irradiation by γ-quanta. According to Fig. 5, which shows the pulse shape over a time range of 5 µsec (R_A = 50 ohm; γ-quanta irradiation), the total rise time of the slow component is τ_A = 0.6 µsec. Its decay time constant, according to Fig. 6, is τ_L = 2.8 µsec. The pulse shape, plotted in Fig. 6 on a semi-logarithmic scale, was measured at an anode time constant which was large compared with τ_s and small compared with τ_L.

2. Application to particle discrimination

The different scintillation behaviour of the CsI crystal when irradiated with alpha particles or γ-quanta suggests a

possible use in particle discrimination. The difference, i.e. the virtual lack of a slow component for alpha particle scintillation, is clearly visible in Fig. 7. In this instance, the anode resistance R_A of the photomultiplier amounted to 12 kohm and the working time constant τ again satisfied the relation $\tau_s \ll \tau \ll \tau_z$. Both pulse shapes were standardised to the same initial intensity. The decay of the alpha particle pulse is determined by time constant τ.

Fig. 8 demonstrates the usefulness of the CsI scintillator in differentiating between alpha particles (the left-hand steep branch) and γ-quanta (the right-hand branch). The photograph was obtained with the aid of an X-Y oscillograph. Each scintillation appears as a spot on the fluorescent screen[14, 15].

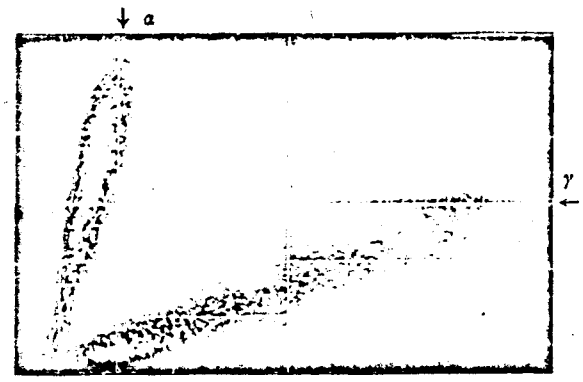

Fig. 8: Particle discrimination with unactivated CsI.

The abscissae of the luminous spots are proportional to the total light yield per scintillation (the height of the output pulse at a working time constant which is large compared with τ_L). The ordinates indicate the intensity of the fast component (the height of the pulse taken at a working resistance R_A = 100 ohms after amplification over a bandwidth of some 3 MHz). The concentrations of luminous spots associated with the alpha particles and quanta are clearly separated from each other, in spite of the comparatively wide scattering due to the low light yield of the crystal.

Unactivated CsI is also suitable for the theoretically simple process of particle discrimination by the "zero crossover method"[16,17]. Here, the pulse shape occurring at an anode time constant R_1C_1 (see fig. 9) (which is, as a rule, large in comparison with the duration of scintillation) is subsequently differentiated at a further time constant R_2C_2.

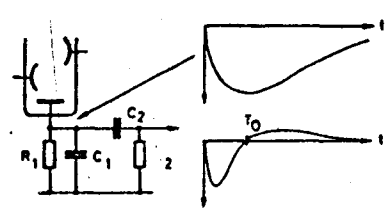

Fig. 9: The zero crossover method.

The pulse is thus given a positive "swing-through", i.e. after a time T_0, its plot passes through the zero line. This zero crossover time T_0 is a function of the time constants R_1C_1 and R_2C_2 and of the duration of the scintillation. It is, however, independent of the pulse amplitude. Hence, if the time constants are predetermined, T_0 is a measure of the duration of the scintillation. If, as in the present case, the latter depends upon the nature of the exciting radiation, T_0 may be used to distinguish between types of radiation. T_0 can be measured in various ways, the most simple one being the use of a Schmitt trigger possessing a suitably adjusted response threshold and hysteresis. Fig. 10 shows a frequency distribution of the zero crossover times T_0 obtained with the aid of a multi-channel spectrometer, with unactivated CsI as the scintillator and alpha particle and γ-quanta irradiation. The optimum values for time constants R_1C_1 and R_2C_2 were determined empirically. In spite of the relatively great width of the two distributions, which is a direct result of the low light zield of the crystal, alpha particles and γ-quanta are clearly distringuishable from each other.

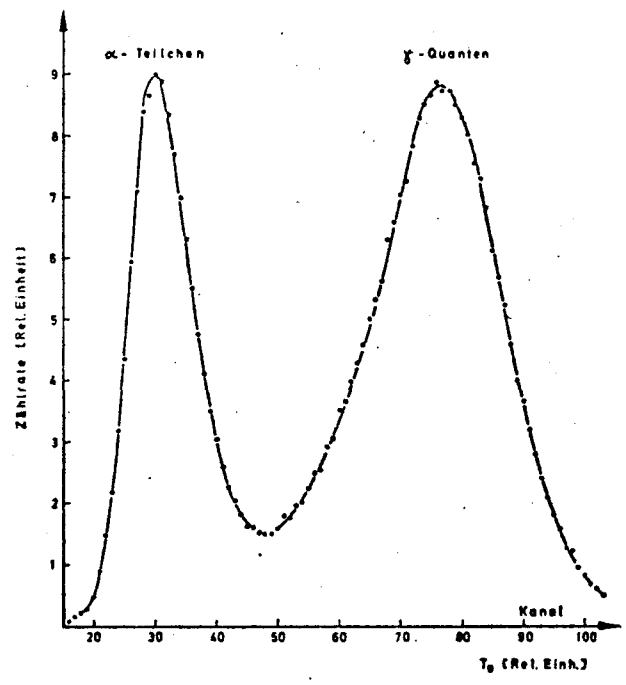

Fig. 10: Particle discrimination with unactivated CsI by the zero crossover method.

Legend: α-Teilchen = alpha particles; γ-Quanten = γ-quanta; Zählrate (Rel. Einheit) = counting rate (relative units); Kanal = channel.

3. Conclusion

The present measurements agree qualitatively with those of Walter[9] and Siemer[10], who also observed at room temperature two scintillation components with widely differing decay times for an unactivated CsI crystal which was likewise drawn from the melt. They were furthermore able to demonstrate unequivocally that these two components can be related to different spectral components of the scintillation light.

According to them, the fast component derives from light in the near ultra-violet range and the slow component from light in the visible spectrum. In their crystal sample, a slow decay component ($\sim$ 0.9 μsec) occurred with a measurable intensity also with alpha particle excitation.

The various investigations of the emission spectrum of unactivated CsI, which consists essentially of two bands, give an idea of the origin of the two scintillation components. The measurements of Besson et al.[18] in particular demonstrate that the short-wave emission band, with a maximum at about 3500 Å, originates from scintillation processes in the basic lattice of the CsI crystal. Referring to similar measurements made by van Sciver[19] on unactivated NaI, its occurrence could be explained by a radiative recombination of excitons. The intensity of the long-wave band observed by Besson et al. at about 4400 Å is very closely related to the degree of purity of the crystal. It drops as the purity of the raw material increases. Research by other authors has shown that the method of drawing the crystals also clearly affects the component in the visible spectrum. It is impossible to say which kind of shortcoming causes the long-wave and slow scintillation.

I should like to thank the Federal Ministry for Education and Science for its financial assistance.

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