

PROCEEDINGS SERIES

NUCLEAR ELECTRONICS I

PROCEEDINGS OF THE CONFERENCE ON
NUCLEAR ELECTRONICS
SPONSORED BY
THE INTERNATIONAL ATOMIC ENERGY AGENCY
AND HELD AT BELGRADE, 15-20 MAY 1961

In three volumes

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FOREWORD

Nuclear instruments are used in almost every phase of atomic energy work, from assessing health hazards and prospecting for nuclear materials to plant control and nuclear physics experiments. The demands on nucleonic instrumentation are growing steadily. High-energy particle physics need such instruments for measuring extremely short times; in various research experiments most advanced electronic systems are required; and routine applications of radioisotopes call for more reliable instruments for automated counting facilities.

In order to give designers and users of nuclear instrumentation an opportunity to discuss the research results and to exchange information on recent developments and new designs, the International Atomic Energy Agency, in co-operation with the Federal Nuclear Energy Commission of Yugoslavia, organized a Conference on Nuclear Electronics which was held in Belgrade from 15—20 May 1961. It was attended by more than 300 scientists from nearly 30 countries and five international organizations. Over 150 papers were read and discussed. As the field of nuclear electronics has expanded considerably, it was impossible to discuss all aspects of nuclear electronics in one series of meetings. Included in the main topics were radiation detectors, electronic circuitry in conventional and fast-pulse techniques and advanced electronic systems used in nuclear research.

The Proceedings presented in these volumes contain the full records of the Conference, including discussions. The present state of technique, together with current trends and developments, are outlined. Of particular value should be the world-wide survey on progress recently made in such fields as those connected with semiconductor detectors, spark counters, luminescence chambers and fast electronic facilities for nuclear physics research. Together with the Proceedings of the Symposium on the same subject held in Paris and also published by the International Atomic Energy Agency, these volumes offer reference materials very useful to scientists and engineers directly engaged in the development and design of nuclear electronic instruments, as well as to all those who use these instruments in their research and routine work—in developed as well as developing countries.

A handwritten signature in dark ink, appearing to read 'H. Downey', is positioned above the title. The signature is fluid and cursive, with a long, sweeping tail that extends to the right.

Scientific Secretary

Conference on Nuclear Electronics

April 1962

EDITORIAL NOTE

The papers and discussions incorporated in proceedings published by the International Atomic Energy Agency are checked for scientific accuracy by the Agency's experts in the subjects concerned and edited by the Agency's editorial staff to the extent considered necessary for the reader's assistance. The views expressed and the general style adopted remain, however, the responsibility of the named authors or participants.

The units and symbols employed are to the fullest practicable extent those standardized or recommended by the competent international scientific bodies. In the present proceedings, however, the non-standard system of symbols in common use in electronics (e.g. $K = k\Omega$) has been accepted in many Figures (to save redrawing costs) but corrected in the text.

The affiliations of authors are those given at the time of nomination.

The names of States mentioned in connection with authors' or participants' names in the titles of papers, the discussions and the lists of participants are those of the Member States which nominated the participants. They do not necessarily reflect the nationality of the participants or the countries of their affiliations. In some cases, participants are nominated by international organizations, the names of which appear in place of those of Member States.

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I.

SCINTILLATION AND CERENKOV DETECTORS

(SESSION 1)

SCINTILLATION PROPERTIES OF PURE ALKALI HALIDES AT LOW TEMPERATURES

H. V. WATTS, L. REIFFEL AND M. D. OESTREICH

ARMOUR RESEARCH FOUNDATION, CHICAGO, ILL.

UNITED STATES OF AMERICA

Abstract — Résumé — Аннотация — Resumen

Scintillation properties of pure alkali halides at low temperatures. Fragmentary studies in various laboratories on the scintillation behaviour of several of the alkali halides, both with and without impurity activators, indicate that in general the activated alkali halides scintillate best at room-temperature with pulse-height decreasing at lower temperatures, while the unactivated materials scintillate best at low temperatures and decrease in efficiency as the temperature increases. In our laboratory, a systematic research study on the scintillation properties of the alkali halides is underway and to date we have examined twelve pure (unactivated) alkali halides with both α -particle and γ -ray excitation over the temperature range of 4°K to 300°K. LiI, KI, and CsI exhibit a constant scintillation pulse-height and decay-time at temperatures below 80°K. NaI exhibits a maximum in pulse-height at 60°K similar to that reported previously by VAN SCIVER *et al.* A second CsI sample shows both a low-temperature scintillation-component and a room-temperature component similar to that induced by over-heating as in the experiments of KNOEPFEL *et al.* RbI shows two regions of linearly decreasing pulse-height as temperature increases. The scintillation pulse-heights of the iodides are comparable to that observed from thallium-activated sodium iodide and the decay times are about 0.1 to 2 μ s. CsBr, KBr, and NaCl scintillate at low temperatures, but with a much lower intensity than the iodides. LiF, NaF, KCl, and RbBr exhibit no detectable scintillation over the entire temperature range studied. The temperature dependence of pulse-heights and decay-constants is the same for both γ and α -excited emission. Analysis of the scintillation pulse-shape and the temperature-dependence gives an indication of the number of luminescence components and the mode of decay of the excited luminescence centres.

Scintillation des halogénures alcalins purs à basse température. Des études fragmentaires effectuées dans divers laboratoires sur le comportement comme scintillateurs de plusieurs halogénures alcalins activés ou non indiquent que, d'une manière générale, les halogénures alcalins activés scintillent le mieux à la température ambiante, l'amplitude des impulsions étant la plus faible aux basses températures; en revanche, les matières non activées scintillent le mieux aux basses températures, leur propriété diminuant lorsque la température augmente. Le laboratoire où les auteurs exercent leur activité a entrepris l'étude systématique de la scintillation des halogénures alcalins et a examiné jusqu'ici le comportement de douze halogénures alcalins purs (non activés) sous l'action de particules α et de rayons γ dans la gamme des températures comprises entre 4°K et 300°K. Pour LiI, KI et CsI, l'amplitude des impulsions et la durée de vie des scintillations sont constantes au-dessous de 80°K. Pour NaI, l'amplitude des impulsions est maximum à 60°K, résultat très semblable à celui dont Van Sciver et coll. ont déjà rendu compte. Un deuxième échantillon de CsI présente à la fois une composante de scintillation aux basses températures et une composante à la température ambiante semblable à celle produite par surchauffe comme dans les expériences de Knoepfel et coll. Pour le RbI, l'amplitude des impulsions décroît lorsque la température augmente et la courbe correspondante est linéaire en deux régions. Les amplitudes des impulsions de scintillation des iodures sont comparables à celles que l'on observe pour l'iodure de sodium activé au thallium, la durée de vie étant de l'ordre de 0,1 à 2 μ s. CsBr, KBr et NaCl scintillent aux basses températures, mais avec une intensité beaucoup plus faible que les iodures. LiF, NaF, KCl et RbBr n'ont pas de propriété de scintillation décelable dans toute la gamme des températures étudiées. Les amplitudes d'impulsions et les constantes de décroissance varient avec la température de la même façon sous l'effet

de rayons γ et sous l'effet de particules α . L'analyse de la forme de l'impulsion de scintillation et de l'influence de la température donne une idée du nombre des composantes de luminescence et du mode de désexcitation des centres luminescents excités.

Сцинтилляционные свойства чистых щелочных галоидов при низких температурах. Проведенные в различных лабораториях отрывочные исследования особенностей сцинтилляции некоторых из щелочных галоидов как с активаторами взвеси, так и без них показывают, что, как общее правило, активированные щелочные галоиды сцинтиллируют лучше всего при комнатной температуре, причем амплитуда импульсов уменьшается по мере падения температуры, тогда как неактивированные материалы сцинтиллируют лучше всего при низких температурах, причем эффективность сцинтилляции падает по мере возрастания температуры. В нашей лаборатории производится в настоящее время систематическое исследование сцинтилляционных свойств щелочных галоидов, и до сих пор мы изучили двенадцать чистых (неактивированных) щелочных галоидов при возбуждении их как альфа-частицами, так и гамма-излучениями, в интервале температур от 4°K до 300°K. LiI, KI и CsI сохраняют постоянную амплитуду сцинтилляционного импульса и постоянное время распада при температурах ниже 80°K. У NaI максимальная амплитуда импульса наблюдается при температуре в 60°K, подобно тому, что сообщалось ранее Ван Сквером и другими. У второго образца CsI наблюдалась составная часть сцинтилляции при низкой температуре и другая составная часть — при комнатной температуре, аналогично тому, что вызывалось в опытах с перегревом, произведенными Кнопфелем и другими. По мере возрастания температуры у RbI наблюдаются две зоны линейнопадающей амплитуды импульса. Амплитуды сцинтилляционных импульсов йодистых соединений сопоставимы с амплитудами, наблюдавшимися с активированным таллием йодистым натрием, а время распада их лежит в пределах порядка от 0,1 до 2 микросекунд. CsBr, KBr и NaCl сцинтиллируют при низких температурах, но с гораздо меньшей интенсивностью, чем йодистые соединения. У LiF, NaF, KCl и RbBr не наблюдается уловимой сцинтилляции во всех изученных температурных интервалах. Зависимость амплитуды импульсов и констант распада от температуры одинакова как для эмиссии, вызванной гамма-излучениями, так и для эмиссии, вызванной альфа-частицами. Анализ формы сцинтилляционных импульсов и зависимости их от температуры дает указание относительно числа люминесцирующих составных частей и способа распада возбужденных центров люминесценции.

Propiedades de centelleo de los haluros alcalinos puros a baja temperatura. Los estudios parciales realizados en varios laboratorios, sobre las propiedades de centelleo de algunos haluros alcalinos, puros y con impurezas activadoras, demuestran que, en general, el centelleo de los haluros alcalinos activados es óptimo a la temperatura ambiente y que la amplitud de los impulsos disminuye con la temperatura, mientras que el centelleo de las sustancias no activadas es óptimo a baja temperatura y su eficiencia disminuye a medida que ésta aumenta. En nuestro laboratorio se está realizando una investigación sistemática sobre las propiedades de centelleo de los haluros alcalinos y hasta ahora se han examinado doce de éstos en estado puro (no activado) utilizando como excitadores partículas alfa y rayos gamma, en un margen de temperaturas desde 4°K a 300°K. El LiI, KI y CsI presentan una amplitud de impulso de centelleo y un tiempo de caída constantes para temperaturas inferiores a 80°K. La amplitud de los impulsos del NaI presenta un máximo para una temperatura de 60°K análogo al señalado anteriormente por Van Sciver y sus colaboradores. En una segunda muestra de CsI, se han observado dos componentes de centelleo; uno, característico de bajas temperaturas, y otro característico de temperaturas ambiente, análogo al inducido por sobrecalentamiento, como en el caso de los experimentos de Knoepfel y sus colaboradores. El RbI presenta dos regiones en que la amplitud de los impulsos es inversamente proporcional a la temperatura. Las amplitudes de los impulsos de centelleo de los yoduros son comparables a las observadas en el yoduro de sodio activado con talio, y los tiempos de caída son del orden de 0,1 a 2 μ s. El CsBr, el KBr y el NaCl emiten centelleos a baja temperatura, pero con una intensidad mucho menor que los yoduros. El LiF, NaF, KCl y RbBr no presentan centelleo detectable en toda la gama de temperaturas estudiada.

La variación de las amplitudes de impulso y de las constantes de tiempo de caída en función de la temperatura es la misma cuando los centelleadores se excitan con rayos gamma que cuando se excitan con partículas alfa. El análisis de la forma de los impulsos y de su variación en función de la temperatura da una indicación relativa al número de componentes y la modalidad de caída de los centros luminiscentes excitados.

I. Introduction and background

Studies in various laboratories on the scintillation behaviour of several of the alkali halides, both with and without impurity activators, indicate that, in general, the activated alkali halides scintillate best at room temperature with pulse-height decreasing at lower temperatures, while the unactivated materials scintillate best at low temperatures and decrease in efficiency as the temperature increases. BONANOMI *et al.* [1] have studied the temperature-dependence of the emission of pure and thallium-activated alkali halides down to 77° K. The scintillation intensity versus temperature from 77° K to 300° K was found to be described fairly well by a function derived under the assumption of two competing temperature-dependent transitions, one radiative, the other non-radiative.

VAN SCIVER [2] [3] has compared the scintillation intensity, decay-time, and spectra of several NaI and NaI(Tl) crystals at low temperatures. He observed a peak in the scintillation intensity of pure NaI at about 80° K. DER MATEOSIAN *et al.* [4] have reported similar results down to 77° K.

KNOEPFEL *et al.* [5] have examined CsI, both pure and activated, down to 77° K. Distinctly different properties were observed for the two types of crystal. The scintillation intensity of thallium-activated CsI remained nearly constant when the temperature was decreased from 300° K to about 160° K and then the intensity decreased with a further decrease in temperature. The decay-time increased continuously as the temperature was lowered through this range. With unactivated CsI, the intensity increased continuously as the sample was cooled down to 77° K and the decay-time remained nearly constant. The intensity of the unactivated samples equalled that of the activated samples at about 160° K. This is similar to the behaviour observed by BONANOMI *et al.* [1] for the pure and unactivated CsI. However, it was found by KNOEPFEL *et al.* [5] that pure CsI would show components of both the activated and unactivated material if it is heated to between 800 and 900° C (MP CsI is 621° C) for about five minutes, and then thermally quenched. The melt must be overheated, not merely heated to the melting point. Because of the fact that iodine was liberated during the overheating, a strong argument is presented in favour of an iodine vacancy rather than a substitutional thallium ion as the luminescence centre. The vacancy is created by the formation of iodine molecules which become incorporated in the crystal lattice in the overheated sample and by a TI-I-complex, behaving in a similar way chemically to the iodine molecule, in the case of a thallium-activated sample.

MURRAY *et al.* [6] [7] have examined the luminescence emission spectra of pure and europium-activated lithium iodide at temperatures down to 77° K. Measurements on the scintillation intensity and decay-time as a function of temperature were also made.

Although considerable interest has been shown in the low-temperature scintillation-properties of alkali halides, only fragmentary work has actually been done, and most of this work has been done only to 77° K. Therefore, systematic research on pure alkali halides was begun in our laboratory. In the investigations currently underway, the

low-temperature scintillation properties of twelve pure (unactivated) alkali halides have been examined down to 4°K.

II. Apparatus and Techniques

Fig. 1 is a cross-section view through the sample compartment of our double-walled liquid-helium dewar. The samples are mounted within a silver-plated copper cylinder which is the bottom end of the liquid-helium reservoir. Good thermal contact is provided by the crystal holder and the crystal mounting geometry surrounds the samples, as much as possible, with the operating temperature of the copper cylinder. A standard heat-radiation shield attached to the liquid-nitrogen reservoir surrounds the sample mount. The temperature is determined by a copper-constant thermocouple, the junction of which is indium soldered to the sample mount.

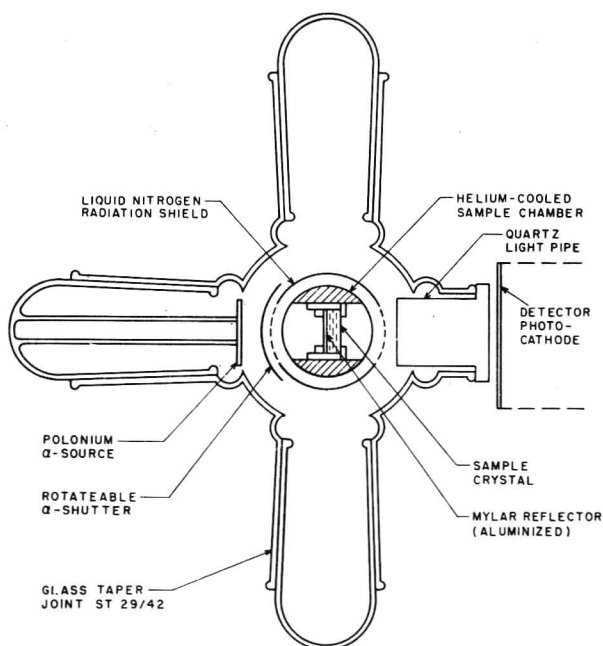


Fig. 1

Cross-section view of sample geometry

Alpha-particle excitation is provided by a polonium-210 source (~ 600 disintegrations/s in forward direction) mounted in the vacuum space of the dewar. A rotatable α -shield is used for stopping the excitation. An external collimated cobalt-60 gamma source was used for γ -excitation.

The source side of the crystal sample is covered by 1/4-mil aluminized mylar as a light reflector for increased scintillation-detection efficiency. The loss in alpha-particle

energy due to this reflector (~ 1 MeV loss) is less than the gain in light-detection which the reflector gives. A cylindrical quartz light-collector is used to further increase the detection geometry or effective aperture.

On the outside of the dewar, optically coupled with silicone fluid (Dow-Corning 600000 silicone fluid) to the quartz light pipe, is the multiplier phototube detector. This tube, DuMont K1306, has a vycor window which extends its spectral response further into the ultraviolet than the standard type 6292 multiplier phototube. The photocathode temperature of this tube remains constant; thus the spectral efficiencies of the detector remain constant throughout the sample temperature region.

The scintillation pulses are viewed and photographed on a Tektronix Model 541 synchroscope with the Tektronix Type L "Hi-gain" pre-amplifier. This system has a combined rise-time of about 10^{-8} s and a sensitivity sufficient to detect the dark noise pulses of the ten-stage multiplier phototube.

If we assume the exponential fluorescence decay, i.e.

$$f(t) = 1/\tau e^{-t/\tau}, \quad (1)$$

the voltage pulse as a function of time on the RC anode circuit is

$$V(t) = \frac{A}{C} \left(\frac{RC}{RC - \tau} \right) (e^{-t/RC} - e^{-t/\tau}) \quad (2)$$

where A = constant which includes the total number of scintillation photons produced by the charged particle excitation and the detection efficiency

C = capacity of the anode circuit

R = anode resistance

τ = exponential decay-time.

If the anode circuit is made to integrate ($RC \gg \tau$) the rise of the pulse will be governed by the decay of the fluorescence pulse and Equation (2) can be rewritten as

$$V(t) = A/C (1 - e^{-t/\tau}). \quad (3)$$

Thus the time for the integrated pulse to reach 0.63 of maximum is the decay-constant, τ . In practice RC is set for about 10 to 50 μ s. The peak pulse-height from Equation (3), A/C , is independent of τ and proportional to the scintillation efficiency or total number of scintillation photons produced.

In our apparatus we may conveniently change the value of the anode resistance R so that the conditions of Equation (3) may be tested. All of the peak pulse-heights reported are integrated pulse-heights, independent of τ .

Twelve samples of pure (unactivated) alkali halides were obtained in crystalline form from two commercial suppliers. Ten of these were from one supplier, Harshaw Chemical Company, Cleveland, Ohio, and were selected from the cones of the ingots where maximum purity is obtained. The other materials were obtained from Semi-Elements, Inc., Saxonburg, Pennsylvania. The twelve alkali halides include:

lithium fluoride	(H)
sodium fluoride	(H)
sodium chloride	(H)
potassium chloride	(H)

potassium bromide	(H)
rubidium bromide	(S)
caesium bromide	(H)
lithium iodide	(H)
sodium iodide	(H)
potassium iodide	(H)
rubidium iodide	(S)
caesium iodide	(S) (H)

The symbols (H) and (S) indicate the material source. Note that caesium iodide samples were obtained from both suppliers.

The Harshaw Chemical Company supplied a qualitative spectrographic analysis of their samples. The most significant impurity noted is a "very faint trace" of thallium in one caesium iodide crystal—henceforth to be called CsI'. The other CsI sample from Harshaw did not have a detectable amount of thallium. No analysis was obtained on the samples from Semi-Elements; however, the suppliers claimed that the CsI had no detectable thallium impurity.

The 1/2-in diam., 3/16-in thick crystals were polished and fitted into the dewar sample-holder. Very hygroscopic crystals were protected with a thin film of glycerol which was found to have no detectable influence on the measured intensity at any temperature.

III. Experimental results

TEMPERATURE DEPENDENCE OF SCINTILLATION INTENSITIES AND TIME-CONSTANTS

Before the discussion of the data, a general summary may be made. All of the un-activated alkali iodides scintillated with good efficiencies at the low temperatures. Around 4° K, KBr and NaCl showed detectable scintillation which was 10 to 20 times lower than that of the iodides. CsBr was examined only to 77° K and the scintillation intensity was found to be considerably lower than that of the iodides. No detectable scintillation was observed from LiF, NaF, KCl, or RbBr.

Figs. 2 to 5 show the temperature-dependence from 4° K to 300° K of the alpha-particle, excited luminescence-intensity and decay-constant for those samples which exhibited detectable luminescence. The luminescence-intensity is the integrated peak pulse-height which, as mentioned previously, is independent of the decay-constant and is directly proportional to the total number of luminescent photons produced by the excitation particle (see Equation 2). These peak pulse-heights are readable to about $\pm 5\%$. Decay-times were determined by the method described in the discussion of Equation (3). These values are readable to about $\pm 5\%$.

The pulse-height scale on the Figures is in arbitrary units which are relatively exact from Figure to Figure. The limit of detectability is 0.01 units on this scale. This is the dark-noise pulse-height of the multiplier phototube. A relative value of the detectability of this system can be assessed by noting that the pulse-height of thallium-activated sodium iodide at room temperature is equivalent to 0.25 units on this intensity scale. Since the readability of this detection system is 1/25 of NaI(Tl), this is equivalent to detecting materials which have about 0.5% luminescence efficiency.*

* The absolute luminescence efficiency of NaI(Tl) has been determined by Van Sciver to be 13% for alpha particles.

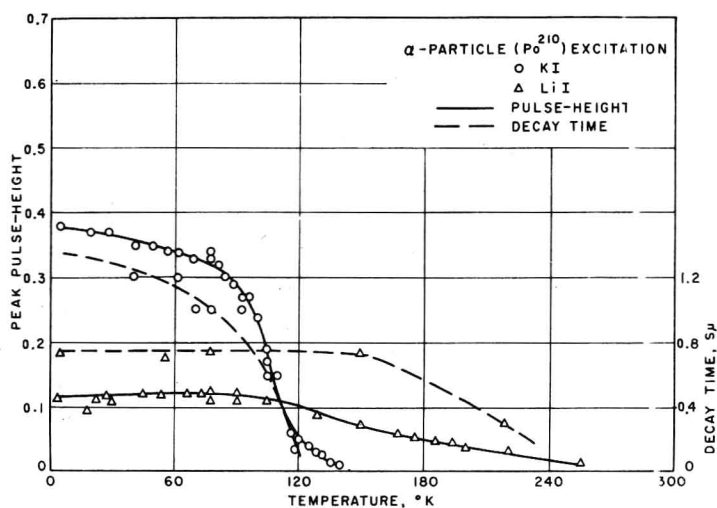


Fig. 2

Scintillation pulse-heights and pulse decay-times as a function of temperature

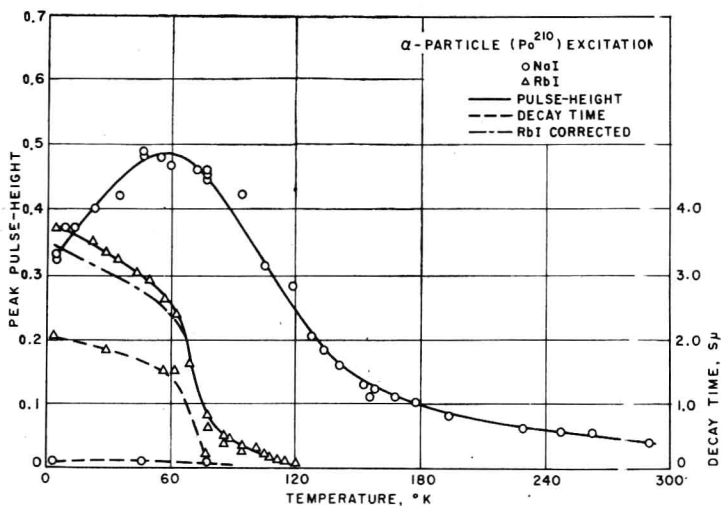


Fig. 3

Scintillation pulse-heights and pulse decay-times as a function of temperature