above 0.55 Mev, as was implied by the absorption measurements referred to. It is believed that absorption methods cannot easily distinguish between a single beta-ray group, on which there is superposed near the high energy end an internal conversion line, and two beta-ray groups.

The internal conversion line has an energy of 0.626 Mev. Adding to this, 0.037 Mev, the binding energy of the K shell for Ba, we find for the energy of the converted gamma-ray 0.663±0.006 Mev. A direct measurement of the gamma-ray energy was made by placing a radiator of lead 0.2 mm thick in front of a sample of Cs^{137} and measuring the energy of the photoelectrons ejected. On adding 0.088 Mev, the binding energy of the K shell in lead to the measured photoelectron energy 0.577 Mev, we obtain for the energy of the gamma-ray 0.665 Mev. No evidence for the presence of any other gamma-ray could be found. The internal conversion coefficient was found to be 0.12.

In summary, this investigation shows that the radiation from Cs^{137} consists of a simple beta-ray spectrum with an end point at 0.550-Mev energy and a single gamma-ray of 0.663-Mev energy, 12 percent of the gamma-ray being internally converted. The monoenergetic nature of the gamma-ray combined with the long half-life of Cs^{137}, 33 years, suggests its use as a gamma-ray standard. Coincidence studies are being made to secure information as to the decay scheme of this isotope. The work was carried out under contract with the Office of Naval Research.

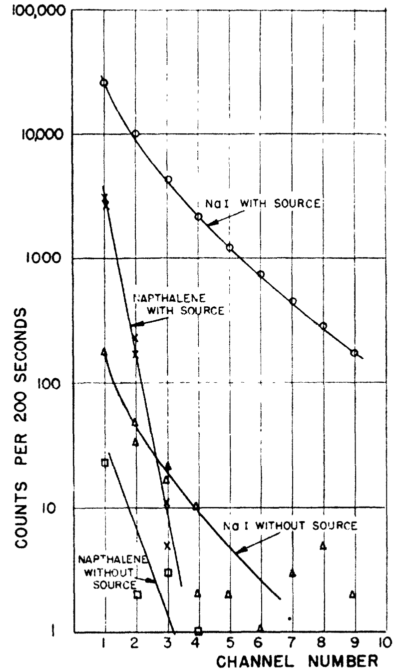

FIG. 2. Differential bias curves for pulses from NaI(Tl) and naphthalene. Channel 1 records pulses in the range 5–10 volts. Channel 2, 10–15 volts, etc.

Alkali Halide Scintillation Counters

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May 20, 1948

IT has been shown by J. W. Coltman, H. Kallman, M. Deutsch, and G. B. Collins[1] that beta-particles and gamma-rays can be detected by the scintillations which these ionizing radiations produce in certain crystals. Among the most successful for practical applications are naphthalene and perhaps anthracene.[2] Such crystals are not particularly suitable for many purposes since their densities are small (about 1 g/cc), their atomic numbers low, and their light flashes are small, so that the photomultiplier detector must be cooled to reduce background noise pulses.

FIG. 1. Oscilloscope screen photographs taken at random for 1/30 second. Above, pulses due to NaI(Tl) and below, pulses due to naphthalene under identical circumstances. Sweep calibration: total length of sweep equals 4.3 microseconds.

From the known properties of the alkali halide phosphors[3] it occurred to the author that these materials, of moderate density (2.0 to 4.5 g/cc), medium atomic numbers, great transparency, and beautiful form, might be very suitable for scintillation counters. The time during which light flashes are emitted is also known to be small, although phosphorescence is observed in some specimens.[4]

The author had in his possession a crystal of potassium iodide with a small thallium impurity (probably 0.1 percent or so) which was kindly provided him a year ago by Mr. Frank B. Quinlan of the General Electric Company. This crystal had been grown in 1938 by Dr. Frederick Seitz and Mr. Quinlan. Accordingly, the author, with the help of Mr. J. C. D. Milton, made an attempt to detect gamma-rays with this crystal and a 931A type photo-multiplier. The attempt was successful and will be described at a later time.

Since potassium is radioactive and, moreover, since the pulses observed in KI were somewhat smaller than those observed with naphthalene samples, the author prepared some powder samples of NaI plus thallium. The results were very encouraging, for pulses caused by alpha-particles were equal, if not greater, than those observed with ZnS (silver), which is known to be a very efficient phosphor. The powder sample proved to be hydroscopic when exexposed to air and, in addition, a yellow film formed on the surface. In a few hours the pulses due to alpha-particles were considerably smaller than the original ones.

Another NaI sample was made in vacuum in a 0.5-inch quartz tube with the result that a mass (~8.0 g) of extremely luminescent small crystals was produced. The crystals are about one or two millimeters on a side. When the quartz tube containing the crystals was placed close to a photo-multiplier, very large pulses were observed from radium gamma-rays. These pulses were larger than those observed with a clear piece of naphthalene (5.8 g) of comparable size. Of course, this NaI sample is completely unaffected by atmospheric conditions and is quite convenient for normal handling. A comparison of results is shown in Figs. 1 and 2. Figure 1 shows oscilloscope pictures of 1/30-second random exposures taken under identical circumstances with the NaI sample and with naphthalene. The source was 0.1-millicurie radium at 16 cm, filtered by 3/32-inch brass. Figure 2 shows a differential bias curve taken under identical conditions for the two materials. From the rise times of the pulses in NaI there is some evidence that the light flashes are emitted in about one microsecond or less. All work reported has been carried on at room temperature.

Further work in progress is designed to produce large single crystals of this and other alkali halides with thallium impurities. A neutron counter using a lithium halide seems to be a reasonable possibility.

In tests made by placing crystals of NaI, KI, and naphthalene on photographic plates (Eastman 103-O) much greater light output was observed from NaI and KI than from naphthalene samples of comparable size. Apparently, naphthalene is not an efficient phosphor.

A sample of NaI in a quartz tube gave measurable blackening of a photographic plate when the combination was exposed for thirty minutes to the gamma-rays of 1.8 millicuries of radium at a meter distance.

A more complete description of these results is being prepared.

The author wishes to thank Professors J. A. Wheeler and R. Sherr for interesting discussions, and Professors M. G. White and H. W. Fulbright for loan of equipment used in these tests.

[1] J. W. Coltman and F. H. Marshall, Phys. Rev. **72**, 528 (1947); H. Kallman, Natur und Technik (July 1947); M. Deutsch, Nucleonics **2**, 58 (1948); G. B. Collins and Rosalie C. Hoyt, Phys. Rev. **73**, 1259 (1948).

[2] P. R. Belland R. C. Davis, Bull. Am. Phys. Soc. **23**, No. 3, 52 (1948). X12.

[3] R. Hilsch, Zeits. f. Physik **44**, 860 (1927); W. von Meyeren, Zeits. f. Physik **61**, 329 (1930).

[4] E. H. Hutten and P. Pringsheim, J. Chem. Phys. **16**, 241 (1948).

An Example of the Beta-Decay of the Light Meson*

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May 17, 1948

THE photographs of Fig. 1 show two views of a large Wilson cloud chamber containing a horizontal lead plate at the top one cm thick, eight aluminum foils each 0.020 cm thick, and two lead plates at the bottom each 0.9 cm thick. The photograph at the left is taken at 21° to that side of normal, while the right view is taken from a symmetrical position on the other side.

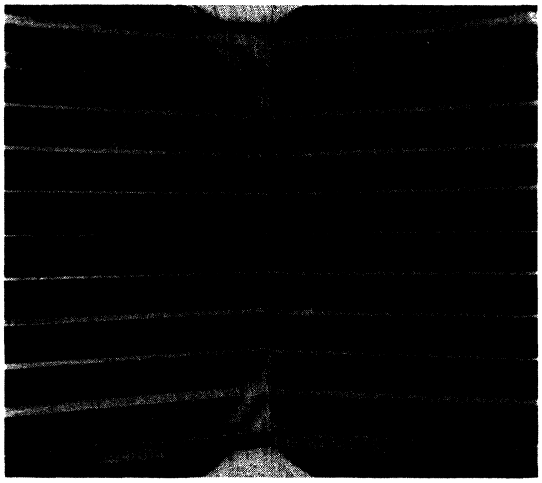

FIG. 1. A meson stops in a foil at the top of the chamber and its decay electron, after penetrating 7 foils, stops in the upper lead plate at the bottom of the chamber. The bright vertical line seen here is a thin wire used as a reference marker.

The nearly horizontal dense track which is seen between the top lead plate and the first aluminum foil, and which appears to stop in the foil, is probably that of a light meson. The density of ionization is between five and ten times the minimum for a singly charged particle. An electron with this ionization would scatter markedly and would have a range of less than two cm in the gas. Hence the observed particle cannot be an electron. A proton with this ionization has a range of more than 0.25 cm of aluminum, and so would be expected to pass through the foil. Reconstruction of the track in space shows that the point where it appears to stop in the foil is well within the region of good illumination. If the scattering of the particle inside the foil is neglected, it has a range of less than 0.10 cm of aluminum. A meson of mass $200m_e$ with this range ionizes 8 times the minimum. Therefore, it seems reasonable to assume that the stopped particle is a light meson.

From the point where the meson stops a particle ionizing less than 2 times minimum is seen to go downward. Its track appears to stop in the upper lead plate at the bottom of the chamber. The point at which the particle strikes the plate is well within the illuminated region. A proton which has a range of less than 0.9 cm of lead ionizes more than 4 times minimum; therefore the observed secondary particle cannot be a proton. In all known cases of the decay of a heavy meson to a light meson (the π–μ-decay) the light meson has an energy of 4 Mev, ionizes 5 times minimum, and has a range of 0.07 cm of aluminum.[1] The event observed here cannot be a π–μ-decay. It seems reasonable, however, to interpret this event as the beta-decay of a light meson. It is evident that the secondary particle ionizes near the minimum and that it is appreciably deflected by scattering in the aluminum foils. Taking this particle to be an electron, it is possible to estimate its

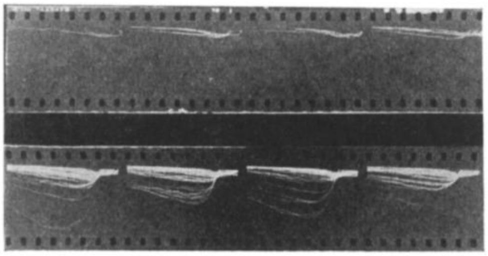

FIG. 1. Oscilloscope screen photographs taken at random for 1/30 second. Above, pulses due to NaI(Tl) and below, pulses due to naphthalene under identical circumstances. Sweep calibration: total length of sweep equals 4.3 microseconds.