Inorganic Crystals for the Detection of High Energy Particles and Quanta

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THIS investigation was suggested by the interesting experiments reported by H. Kallmann[1] on the counting of high energy particles and quanta by the photoelectric detection of individual light flashes. Selected 1P28 and 1P21 photo-multiplier tubes were employed for the detection of the scintillations, and a variety of crystals were employed for the scintillating material. A 10,000-ohm resistor was used in the anode circuit of the photomultiplier tube in which pulse voltages up to 50 millivolts were developed and were further amplified and fed into a scale of 128. Pulses from the photo-multiplier which were less than 1 millivolt were not counted by the scaler. This level corresponded to approximately 10 photoelectrons, or with an estimated geometry of 10 percent and a photocathode yield of one photoelectron per fifty quanta it would correspond to approximately five thousand quanta liberated in the crystal. The pulses reached their maximum value in about one-half microsecond, and the duration of the pulse was approximately one microsecond although the capacity of the cable from output of the photo-multiplier to input of the amplifier contributed to the lengthening of the pulse.

As is usually done, spurious pulses which originate in the photo-multiplier tube were practically eliminated by tube selection and by cooling the tube with solid CO_2. In addition, other spurious pulses originated in the crystals. For example: CaF_2 (clear crystals both artificial and natural) produced scintillations in the absence of radiation. After exposing these crystals to ultraviolet light they showed visible phosphorescence and the next day were producing some two hundred pulses per second. Upon cooling with solid CO_2 this was reduced to less than twenty pulses per second. Similarly, such exposed crystals showed thermal luminescence upon heating to 100°C, which died away upon prolonged heating. After cooling to room temperature in the dark, these crystals were no longer sources of spurious pulses. After all precautions had been taken to reduce background effects, the counting rate became one count per second, mainly because of cosmic rays.

Many inorganic crystals were tried. Calcium tungstate (Scheelite) was by far the best. Its high density of six grams per cubic centimeter, high atomic weight components, and excellent fluorescent properties with minor phosphorescence make it well suited for the detection of beta- and gamma-radiation. Table I lists the various materials investigated.

TABLE I.

I. Excellent response	II. Fair response
$CaWO_4$ (Scheelite)	$PbCO_3$ (cerusite)
CaF_2 (synthetic and natural fluorite)	Phenatite
$LiAlSi_2O_6$ (Spodumene)	Apatite (pale yellow)
Al_2O_3 (synthetic sapphire)	$CaB_2Si_2O_8$ (danburite)
LiF (synthetic)	
III. Medium response	IV. Weak response
$MgSO_4KCl3H_2O$ (Kainite)	$SrSO_4$ (celestite)
Topaz	Tourmaline (pink)
$Be_3Al_2Si_6O_{18}$ (beryl)	$CaSo_42H_2O$ (gypsum)
$CaCO_3$ (calcite)	$CaBSiO_4(OH)$ (datolite)
Sulfur	Maple syrup sugar crystal
	Halite (NaCl)
	NaCl (artificial)
V. No response	
SiO_2 (clear quartz)	$KAlSi_3O_8$ (orthoclase)
$CoCO_3$ (aragonite)	$KMg_2Al_2Si_3O_{10}(OH)_2$ (phologopite)
Al_2O_3+Cr (artificial ruby)	$KAl_3Si_3O_{10}(OH)_2$ (muscovite)
	KCl (artificial)

It may be noted that the variety of elements as well as the nature of the crystal affords many possibilities for radiation detectors. For example, Al_2O_3 (synthetic sapphire), with a hardness next to diamond, could serve both as a durable window to a photo-multiplier tube and as the scintillating material. Such a tube would probably be most useful in a linear form. Crystals which contain boron would be useful detectors for neutrons.

Naphthalene and $CaWO_4$ were compared. A clear naphthalene crystal, 9 g in weight, 4.5 cm long, and having a polished face 11 mm×16 mm yielded less than one-third the number of pulses per second as a 9.3-g $CaWO_4$ crystal with a 7-mm×10-mm polished face, whereas an 8-mm naphthalene crystal of 4.0 g with a 20-mm×20-mm face yielded less than one-sixth the number of pulses per second due to gamma-rays of radium, and yet the tungstate and the naphthalene were equally sensitive to electrons from a radium $D+E$ source. The geometry attained with electrons was nearly 40 percent in both cases. Pulse height and shape were indistinguishable for the two compounds, and the maximum pulses corresponded to some 200,000 quanta per gamma-ray.

An 11.3-g $CaWO_4$ crystal with a 2.16-cm^2 polished face was compared with a standard thin walled glass Geiger-Müller counter 18 mm in diameter×60 mm in length, and the crystal yielded 25 times as many counts per second as the G-M tube with the source at 54 cm; if the ratio of areas is taken into account, the crystal is 125 times more sensitive.

A 100-microgram radium standard at a distance of 54 cm produced 470 counts per second through the 2.16 cm^2 of the calcium tungstate crystal which corresponds to 2.18 gamma-photons per disintegration of radium in equilibrium with its daughter products. These results indicate nearly a 100 percent counting efficiency.

The results with calcium tungstate are contrary to those of H. Kallmann, who found no trace of pulses with calcium tungstate of any thickness of the phosphor layer and a saturated response to gamma-rays with a tungstate thickness of 0.2 mm. This discrepancy between the results may be accounted for if Kallmann used powdered tungstate instead of large clear crystalline lumps, or perhaps his tungstate contained some impurity which damped or absorbed the fluorescence, such as in the case of synthetic ruby where a small amount of chromium is added to aluminum oxide.

[1] H. Kallmann, Nature and Technik (July 1947).