Fluorescent Response of Cesium Iodide Crystals to Heavy Ions*

A. R. QUINTON, C. E. ANDERSON, AND W. J. KNOX
Heavy Ion Accelerator Laboratory, Yale University, New Haven, Connecticut

(Received March 23, 1959)

The light output from thallium-activated cesium iodide crystals has been determined using C^{12}, N^{14}, and O^{16} as incident particles, with energies up to 10 Mev per nucleon. A photocathode with S-11 response viewed the scintillator light and the photomultiplier pulses were compared with those produced by alpha particles and protons of known energies. There is evidence that low-energy heavy ions are inefficient producers of light in this spectral region.

INTRODUCTION

If a scintillation spectrometer is selected for detection purposes in nuclear reaction studies, it is clearly important to measure the response of the scintillating material for various particles as a function of energy. When the reactions are brought about by heavy ions there is an increased need for such a calibration because of the variety of scattered particles and reaction products expected. Because of its ease in handling, cesium iodide suggests itself as a suitable phosphor even though its light output is less than that from sodium iodide under the same conditions. When one wishes to detect low-energy particles in a spectrometer which may involve, say, gas flow also, then cesium iodide becomes the obvious choice and is currently being used in this way in this laboratory.

Apart from these considerations, a study of the light output from a scintillator has intrinsic interest. One might hope to learn from such work, for example, details of the mechanism of energy transfer from a charged particle to its crystal environment.

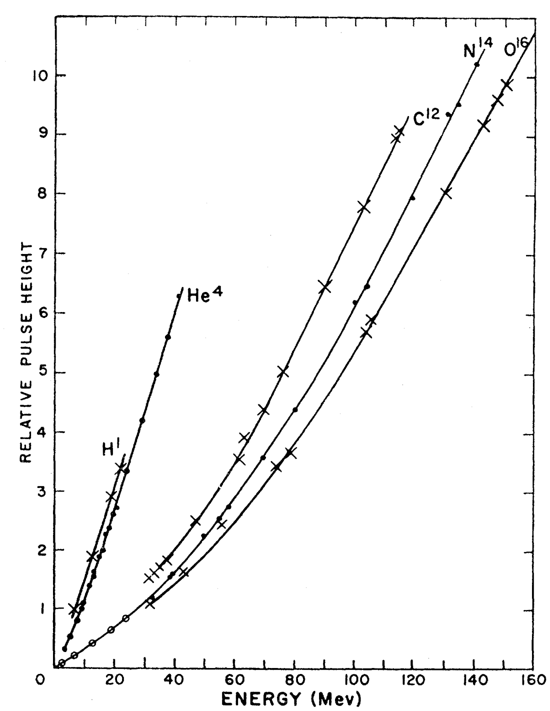

FIG. 1. The relative pulse-height response of CsI *versus* particle energy. (Halbert's data O.)

* This work was supported by the U. S. Atomic Energy Commission.

EXPERIMENTAL METHOD

At the time of this work the Yale heavy-ion accelerator was capable of producing beams of helium, carbon, nitrogen, and oxygen ions at energies of about 10 Mev per nucleon. The charge states for acceleration were mainly 2^+, 5^+, 5^+, and 6^+, respectively, and beam currents were typically 10^{-9} ampere when time-averaged. The appropriate beam was stripped of its remaining electrons by allowing it to pass through a $\frac{1}{4}$-mil Melinex foil and then was degraded in energy by aluminum foils. The particles were next deflected by a calibrated analyzing magnet and collimated onto a thin gold target of about 180 μg/cm^2 superficial density in a simple scattering chamber. Elastically scattered heavy ions of known energy, corrected for recoil, could then enter the cessium iodide detecting crystal, placed at a selected angle, usually 25°, with respect to the beam.

The scintillator was about $\frac{5}{16}$ in. thick and was optically coupled by silicone oil onto a Lucite light pipe which in its turn was coupled in the standard fashion to an RCA6342 10-stage phototube. The incident-particle face of the crystal was polished, in some cases with a moistened soft cloth and in others with cerium oxide. Experimental results did not appear sensitive to this surface treatment. No front face reflector was used.

The phototube was operated at 750 volts and care taken not to overload the cathode follower which was used to couple the pulses to the transmission cable. The pulses, integrated to a length of about 50 μsec, were amplified and clipped to 1 μsec by a Baird-Atomic 218 amplifier and analyzed by a 20-channel pulse sorter made by the same company.

In practice two detectors were used, largely for check purposes. Each used a thick thallium-activated cesium iodide crystal made by the Harshaw Chemical Company. However, in front of one a gas proportional counter was mounted. This counter was used for gating purposes occasionally, although it was constructed primarily for proton and alpha-particle identification in other experiments. It contained P-10 counter gas and had a $\frac{1}{4}$-mil aluminized Mylar window. The energy of the detected particles was corrected, using our own data, for energy losses in the window and the gas. Good agreement was obtained between the results for the two crystals.

The range of input pulse heights over which the electronics remained linear was checked using a thorium $C-C'$ source. The ratio of the 8.8-Mev alpha-particle pulse height to that from the 6.1-Mev particles was measured as the high voltage on the phototube was varied. A lowering of this ratio indicated the onset of nonlinearity and suggested a safe maximum input pulse height.

An essential part of the experiment was the calibration of the analyzing magnet. This was done using the helium beam and finding the absorber thickness such that scattered particles produced the same pulse height in the detector as the 8.8-Mev natural alpha particles. Then the published range-energy relation for helium ions[1] allowed one to deduce the incident beam energy or to send into the magnet alpha particles of any desired energy up to the maximum. Observation of the corresponding magnet currents resulted in a magnet calibration. At the same time the scintillation response of cesium iodide to helium ions was obtained.

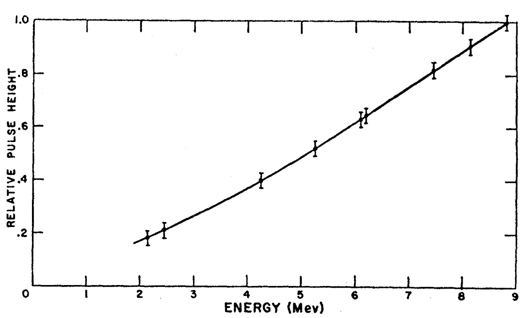

FIG. 2. The low-energy response to alpha particles (all pulse heights are plotted relative to that from 8.8-Mev alpha particles).

The presumption was made that at 10 Mev per nucleon the ions were completely stripped of their electrons if allowed to pass through a $\frac{1}{4}$ mil of Melinex. Hence the charge state was always known. For a few low-energy points, ions carrying one electron passed through the magnet but this condition was readily detected by the trend of the curve of pulse height *versus* energy.

The proton curve was determined by substituting a thin polyethylene foil for the gold target and using a full-energy helium beam. Recoiling protons were then detected at a variety of angles and their energies inferred from kinematical considerations.

It was found more convenient for energies of alpha particles less than 8 Mev to use a natural source of particles and air for energy degradation. The results are shown in Fig. 2. Besides its intrinsic interest it was felt that low-energy alpha data would show up surface effects such as a nonscintillating layer of significant thickness.

[1] W. Whaling, *Handbuch der Physik* (Springer-Verlag, Berlin, 1957), Vol. 34, p. 210.

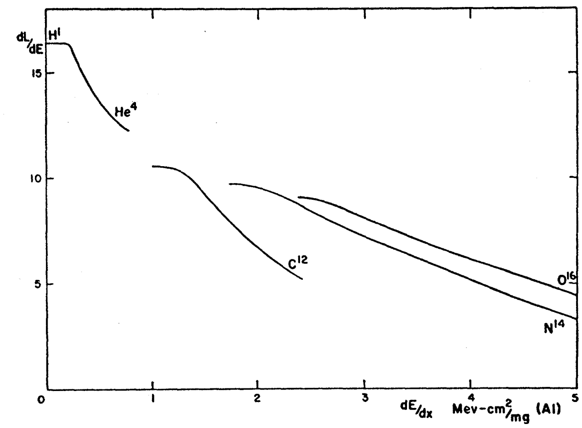

FIG. 3. Plots of the differential light output *versus* differential energy loss of the ions in aluminum.

RESULTS

The experimental results are shown in Figs. 1 and 2. Within the accuracy of our measurements the proton response curve is linear and passes through the origin. The helium curve is displaced about 2 Mev from the proton curve with the linear region starting near 8 Mev. Considerable nonlinearity is apparent with the heavier particles at low energies but the response becomes close to linear above about 70 Mev. Our results stop at a degraded energy near 30 Mev but in the case of N^{14} the work of Halbert[2] is available and has been suitably normalized and added to our curve.

Data of this type are frequently analyzed by plotting the light output per unit path (dL/dx), in the scintillator, as a function of the energy loss per unit path (dE/dx). Unfortunately at this time range-energy relations are not available for heavy ions in cesium iodide or in fact for any material other than aluminum at energies of interest here. However, if one assumes that the stopping-power velocity dependence is the same for heavy ions as for alpha particles, then a plot of dL/dx *versus* dE/dx can be made using the available range-energy relations in aluminum.[3] When this is done it is strongly suggested by the curves that, besides a saturation effect at high dE/dx, some other competing energy-loss mechanism, less efficient in the production of light, comes into play, at an energy specific to each ionic species. Alternatively as in Fig. 3, a plot of dL/dE as a function of dE/dx in aluminum can be made. Again it is clear that the differential light output does not depend only on the differential energy loss.

The light output response of cesium iodide and other scintillators to a variety of incident particles is being studied in more detail by others in this laboratory and will be published later.

ACKNOWLEDGMENTS

The authors are indebted to J. C. Watson, Robert Long, and Harold C. Britt for help in various phases of this work.

[2] M. L. Halbert, Phys. Rev. **107**, 647 (1957).
[3] L. C. Northcliffe (private communication).