TABLE VI. Comparison of two groups of penetrating showers.

Range of electron shower energies (ev)	Estimated average energy (ev)	Average number of penetrating secondaries per event
$0-7\times10^9$	3×10^{10}	7 ± 1
$>7\times10^9$	6×10^{10}	11 ± 2

Multiplicities of High Energy Secondary Particles

As is seen from Table VI, the multiplicities of minimum ionization penetrating secondary particles originating in the initial nuclear encounter are 7 and 11, respectively, for the lower and the higher energy events. A comparison with the number of π-mesons predicted at each of these energies by Fermi[24] shows that the number of particles observed is approximately 3 times higher than those predicted. The difference is attributable partly to the presence of protons among the penetrating ionizing secondary particles and partly to the plural production of secondary particles. It is felt that the existing uncertainties in the interpretation of the results of this experiment are too large to enable a quantitative comparison to be made.

In accordance with the momenta determined from scatterings (Tables III and IV), if the average energy of the secondary particles is estimated to be 4×10^9 ev, then the multiplicities of 7 and 11 given in Table VI indicate that the energies of the two groups of events are 3×10^{10} and 4×10^{10} ev per shower, respectively. When the energy of the electron showers is added to these values, the agreement with the estimated energies of the initiating particles of the two groups of showers is satisfactory.

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Response of an Anthracene Scintillation Counter to Protons*

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The proton response of an anthracene scintillation counter below 3.7 Mev has been measured. When combined with previously published data up to 17 Mev, a smooth curve results. An attempt was made to correlate the efficiency of the light output with the ion density by plotting the differential light output as a function of the differential energy absorption for both electrons and protons. The available information is not sufficiently extensive or accurate to determine whether or not the proton and electron data coincide.

I. INTRODUCTION

A SCINTILLATION counter constructed with a hydrogen-containing phosphor has frequently been suggested as a detector of fast neutrons. This device actually detects recoil protons from the hydrogen within the crystal. Interpretation of the pulse-height distribution caused by neutrons is possible only if the response of the phosphor to protons is known. A direct measurement, described in this paper, has been made of the response of an anthracene scintillation counter to protons having energies below 3.7 Mev, and these data have been combined with previously published data at higher energies. A test was also made of the possibility that the efficiency of light output depends only on ion density.

II. MEASUREMENTS

The M.I.T. Rockefeller electrostatic generator was used as a source of essentially monoenergetic protons. A few of the protons were scattered from the main beam through 90° by a 1.5-mg/cm^2 gold leaf. Protons impinged directly on the front face of a 0.5 in. thick, 0.5 in. diameter clear anthracene crystal, which was mounted by canada balsam on the cathode end of an RCA 5819 photomultiplier tube. The gold foil, crystal, and cathode end of the photomultiplier were mounted in an evacuated *T* section of pipe. Counting rates obtained with a single-channel differential discriminator were normalized to beam intensity, as indicated by a monitor channel.[1]

The output pulse caused by the 624-kev internal-conversion electrons[2] from a small sample of Cs^{137} within the vacuum system was used as a reference level

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[2] L. M. Langer and R. D. Moffat, Phys. Rev. 78, 74 (1950).

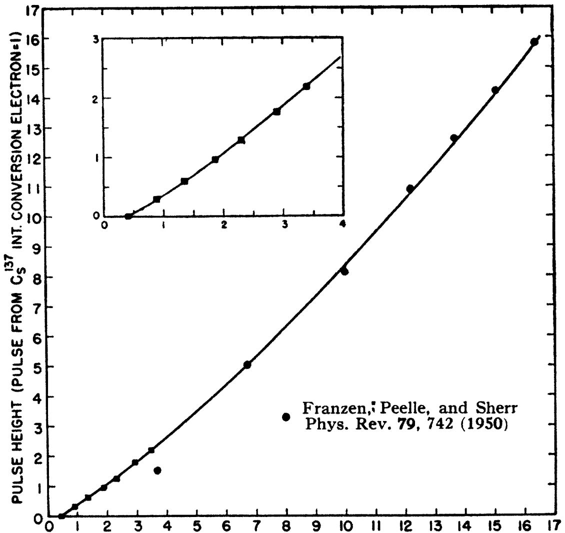

FIG. 1. Light output as a function of proton energy for an anthracene scintillation counter. The insert is an enlarged portion showing the new data below 3.7 Mev. Although 0.4-Mev protons were easily detected, the most probable pulse height could not be separated from dark current with the data taken.

for the proton measurements.[3] Since Cs^{137} emits two beta-particles, in addition to an internal-conversion electron, an approximate beta-curve was subtracted from the total curve of counting rate *vs* differential pulse height[4] to locate more closely the peak of the internal-conversion-electron curve.

III. RESULTS

The insert in Fig. 1, an expanded portion of Fig. 1, shows the relation between the energy of the incident proton and the most probable light-pulse amplitude for the heretofore unreported region below 3.7 Mev. The ordinate of each of the points on the curve represents the pulse amplitude of the peak of a pulse-height distribution curve containing approximately eight points taken for each of the seven proton energies plotted. The energies were measured on a generating voltmeter calibrated with the $Li^7(p,n)$ threshold at 1.882 Mev. The width of the distribution curves is in good agreement with that given by Morton[5] for scintillation counters. A correction of approximately 0.1 Mev has been applied to the initial proton energies to account for the average loss in the gold scattering foil.

When the data mentioned above and those published by Franzen, Peelle, and Sherr are plotted to the same scale, the smooth curve of Fig. 1 is obtained. Only their point at 3.7 Mev, the exact energy of which they questioned, fails to fall close to the curve.

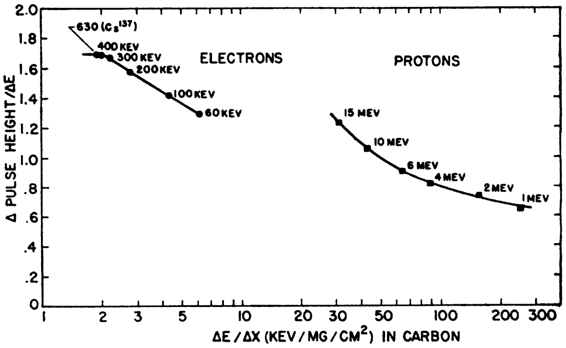

FIG. 2. Differential light output obtained from Fig. 1 as a function of the differential energy loss. The electron and proton data were normalized to the light output caused by the 624-kev Cs^{137} electron.

The fact that protons and alpha-particles produce smaller light pulses than do electrons of equal energy[4] is usually attributed to a saturation effect arising from the much higher specific ionization (at equal energies) of the heavier particles. The slope of curves like Fig. 1 gives the differential light output as a function of energy, dL/dE. The rate of energy loss of electrons[6] and protons,[7] dE/dx, is known. Hence, one can plot curves showing dL/dE as a function of dE/dx for both protons and electrons. Since the specific ionization is nearly proportional to dE/dx and the energy loss per ion formed is about the same for protons and electrons, one might expect that the two curves would coincide roughly if the efficiency of light output in fact depends only on the ion density. Such a plot is shown in Fig. 2. The proton information is taken from Fig. 1 and that for electrons from Hopkins.[8] Because the data available are less reliable at lower than at high energies, the values of the slope, dL/dE, at low energies may be only approximate. The two curves show the expected trend, individually. Their apparent failure to coincide may be due to insufficiently accurate data or to an unknown dependence of light output on factors other than rate of energy loss. Additional information will be required on the differential light output caused by protons at higher energies and electrons at lower energies in order to test further the theory.

We are indebted to Dr. Clark Goodman for his constant encouragement and interest in this work.

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