IONIZATION ENERGY LOSSES OF FAST ELECTRONS IN THIN POLYSTYRENE FILMS

A. I. ALIKHANYAN, A. K. VAL'TER, G. M. GARIBYAN, I. A. GRISHAEV, M. P. LORIKYAN, V. V. PETRENKO, and G. D. FURSOV

Physics Institute, State Atomic Energy Commission, Erevan; Physico-technical Institute, Academy of Sciences, Ukrainian S.S.R.

Submitted to JETP editor October 19, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **46**, 1212-1215 (April, 1964)

The dependence of the ionization energy loss by electrons on the electron momentum was investigated experimentally. It is shown that in films up to 2×10^{-5} cm thick the ionization losses increase logarithmically with increase of the momentum.

ACCORDING to the calculation of Bethe and Bloch, the average ionization losses of the energy of a charged particle per 1 g/cm^2 of matter, when the maximum transferred energy is less than E_0, are given by the formula

$$-\frac{1}{\rho}\frac{dE}{dx} = \frac{B}{\beta^2}\left[\ln\frac{2mc^2\beta^2E_0}{(1-\beta^2)J^2(z)} - \beta^2\right], \qquad (1)$$

where the constant B is governed only by the composition of the material. This formula was calculated without allowing for the effect of the polarization of the material which—as is known—destroys the dependence of dE/dx on the particle momentum at high particle energies. If we use the expression for the polarization effect obtained by Sternheimer,[1] Eq. (1) for high-energy electrons becomes:

$$-\frac{dE}{\rho dx} = B\left[\ln\frac{2mc^2\beta^2E_0}{J^2(z)} - 1 - c_0\right], \qquad (2)$$

where c_0 is another constant governed by the composition of the material.

Garibyan[2] showed that if the thickness of the plate traversed by the particle is less than a certain critical value a, the influence of the polarization of the medium disappears and, consequently the ionization losses are then given by formula (1).

The following expression was obtained for the critical thickness:

$$a = \frac{2cI}{\sigma\hbar}\ln\frac{v\chi_0\hbar}{\sqrt{1-(v/c)^2}\,I}, \qquad (3)$$

where v is the particle velocity, I is the ionization potential of the K-shell, $\sigma = 4\pi Ne^2/m$ is the plasma frequency, and $\chi_0 = 10^7$ cm.

Earlier[3], we investigated the electron energy losses in polystyrene films 10^{-6} cm and 2×10^{-3} cm thick. In the present work, we measured the energy losses in polystyrene films 10^{-5}, 2×10^{-5}, and 2×10^{-4} cm thick.

MEASUREMENT METHOD AND RESULTS

The measurements were carried out using the linear electron accelerator of the Khar'kov Physico-technical Institute of the Ukrainian Academy of Sciences. The accelerator produces pulses of 50 cps repetition frequency.

The experimental layout is shown schematically in Fig. 1.

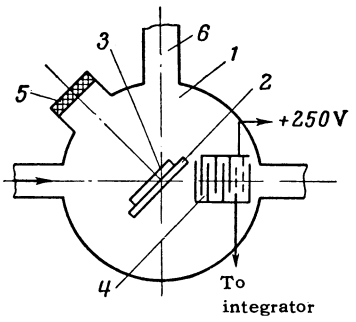

FIG. 1. Schematic representation of the experimental setup: 1) vacuum chamber; 2) target support; 3) zinc sulfide screen; 4) secondary-emission monitor; 5) window for observing the beam image on the screen; 6) light guide. The arrow on the right shows the direction of the electron beam.

The electron beam was focused on the target. A scintillator-loaded polystyrene film, deposited on a thin smooth aluminum substrate, served as the target. The target was prepared as follows: a polystyrene-based benzene solution of a scintillator, of known concentration, was deposited on the substrate. After evaporating the solvent, a thin scintillator film remained on the substrate, the thickness of the film being determined by the concentration and amount of the solution and by the area of the substrate.

To focus a beam of given diameter onto a given spot, a screen of zinc sulfide, incorporating a co-

ordinate grid, was placed in front of the target. After forming the beam, the screen was automatically removed and the target inserted. The position of the beam on the screen was checked with a television camera through a special vacuum window.

Behind the target, a secondary-emission monitor was placed for measuring the number of electrons passing through the target.

The dependence of the secondary-emission coefficient of the monitor on the electron energy is shown in Fig. 2. It is evident that this coefficient is independent of the energy within the range of energies used by us. Light from the target was led to a photomultiplier (type FÉU-13) by a Duralumin light guide 2.5 m long and 60 mm in diameter. To protect the photomultiplier from the effect of radiation generated by the accelerator, the former was surrounded on all sides by a shield comprising 50 cm of concrete and 35 cm of lead.

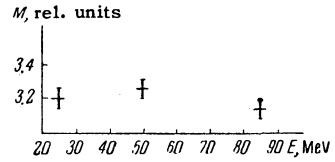

FIG. 2. Dependence of the secondary-emission monitor efficiency on the electron energy.

Since it was impossible to measure the scintillations produced by individual electrons in such very thin films, we used the method of integrating electrical pulses by an RC-circuit at the photomultiplier output, the decay time for this circuit being $\tau = 60\,\mu$sec, which was 30 times longer than the duration of an electron bunch produced by the accelerator. It is clear that under these conditions the whole electron bunch passed through the target during the decay of the pulse and the amplitudes of the pulses due to all the electrons were summed. The pulses were amplified with an amplifier (type USh-2) and fed to a multichannel pulse-height analyzer, with a linear characteristic, which measured the pulse amplitudes and integrated them. Thus we obtained the sum of the scintillation amplitudes of all the electrons which have passed through the target.

If a_i is the amplitude of a scintillation due to one electron and n is the number of electrons, then the average amplitude of a scintillation due to one electron is

$$\frac{\sum_{i=1}^{n} a_i}{n} = W_0.$$

We shall call this quantity the specific scintillation. The method used made it possible to find Σa_i for a given value of n, which simplified the treatment of the results.

First of all, we investigated the dependence of the sum a_i on the number of electrons which passed through the target. The results showed that this dependence is linear within the range of currents used in our measurements. The results are shown in Fig. 3. We investigated also the behavior of the specific scintillation as a function of the duration of irradiation. The results are shown in Fig. 4. The initial fall of the quantity W_0 is obviously due to the evaporation of the weakly bound part of the scintillator surface and the change of its quality. In view of this, the test films were subjected to a preliminary irradiation until the initial decrease of the specific scintillation stopped.

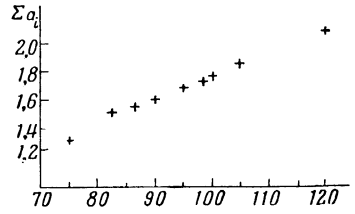

FIG. 3. Dependence of the sum of the scintillation amplitudes of a film on the number of electrons. The abscissa gives the current $I \times 10^{-9}$, in A.

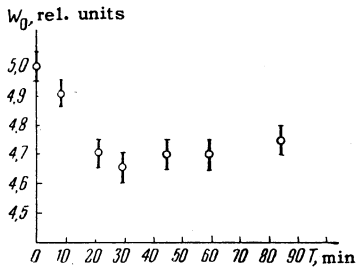

FIG. 4. Dependence of the specific scintillation of a film on the duration of irradiation.

The operational stability of the whole measuring system was checked by flashing a neon lamp whose emission stability was established earlier: in 10 hours of continuous operation, this emission varied within the limits of ± 1%.

Figures 5—7 show the results of measurements of the dependence of the specific scintillation on the electron momentum for films whose thicknesses were of the order of 10^{-5}, 2×10^{-5}, and 2×10^{-4} cm, respectively.

Our measurements of the ionization losses were not absolute but relative since we measured only

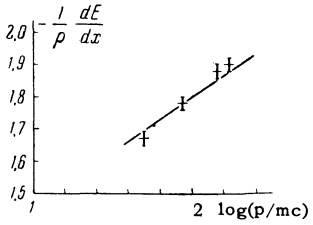

FIG. 5. Theoretical curve and experimental values (+) of the electron energy losses in a polystyrene film 10^{-5} cm thick.

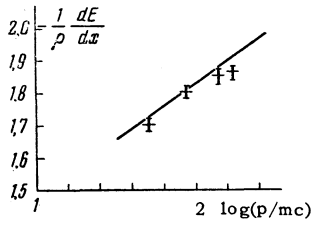

FIG. 6. Theoretical curve and experimental values (+) of the electron energy losses in a polystyrene film 2×10^{-5} cm thick.

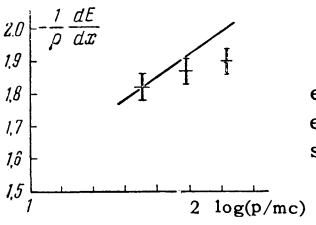

FIG. 7. Theoretical curve and experimental values (+) of the electron energy losses in a polystyrene film 2×10^{-4} cm thick.

the dependence of the specific scintillation of the film on the electron momentum. Therefore, for comparison with Eq. (1), we superimposed one of the experimental points on the corresponding theoretical value. The positions of the remaining points then showed clearly the degree of deviation of experiment from theory. In Figs. 5 and 6, the theoretical and experimental values were made to coincide at an energy of 46 MeV, and in Fig. 7, at an energy of 25 MeV. In all these figures, the continuous curves represent formula (1).

The final results were obtained after correcting for multiple scattering of electrons in the film.[4]

The relatively high value of the experimental error for films 2×10^{-4} cm thick was due to the fact that, with increase of the film thickness, it was necessary to reduce the electron beam intensity in order not to go beyond the linear region of the operation of the measuring apparatus. This in turn led to an increase of the error in the measurement of the current.

The results obtained show that with increase of the electron energy the specific scintillation increases in accordance with Eq. (1) up to film thicknesses of the order of 2×10^{-5} cm, in accordance with Eq. (1), but in a film 2×10^{-4} cm thick the rise is half the theoretical value.

CONCLUSIONS

On the basis of these measurements and the earlier ones,[3] the following conclusion can be drawn. The ionization losses of the electron energy in polystyrene films of thickness equal to, or less than, the critical value are in good agreement with the theoretical predictions[2] within the energy range 20—86 MeV. At thicknesses greater than critical, the influence of the polarization effect begins to be felt and this influence increases with the thickness.

The authors thank Prof. V. M. Kharitonov and V. I. Startsev for their help in this work. The authors thank also the operating personnel of the accelerator whose efforts helped to complete successfully the present work.

[1] R. M. Sternheimer, Phys. Rev. **103**, 511 (1956).

[2] G. M. Garibyan, JETP **37**, 527 (1959), Soviet Phys. JETP **10**, 372 (1960).

[3] Alikhanyan, Garibyan, Lorikyan, Val'ter, Grishaev, Petrenko, and Fursov, JETP **44**, 1122 (1963), Soviet Phys. JETP **17**, 756 (1963).

[4] I. Ya. Pomeranchuk, JETP **18**, 759 (1948).

Translated by A. Tybulewicz
173