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TRANSITION RADIATION FROM RELATIVISTIC CHARGED PARTICLES AND ITS ENERGY DEPENDENCE*

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Transition radiation in the optical region of the spectrum from individual charged pions and protons in the momentum region of 0.8 to 3.5 BeV/c was obtained from a stack of thin metal foils spaced uniformly in vacuum. The radiation was observed simultaneously in the forward and in the backward directions, with a forward-to-backward intensity ratio of the order of 8 to 1. A logarithmic increase in the intensity of the transition radiation with the total energy of the particle is found in the momentum region of the present investigation.

Transition radiation from charged particles traversing the interface between two media of different dielectric properties was first proposed theoretically by Ginzburg and Frank.[1] Subsequently many investigations, both theoretical and experimental, were made.[2] Most of the experimental investigations in the past delt with sizable currents of charged particles in the nonrelativistic region. More recently, Alikhanian[3] observed the x-ray spectrum of the transition radiation from cosmic-ray muons in the energy region around 1000 BeV. Experimental observation of the optical spectrum from relativistic electrons was also made recently[4] from a beta-ray source. However, no quantitative information has yet been obtained on the energy dependence of the intensity of the transition radiation for charged particles in the relativistic region. This is especially true for particles heavier than electrons. Such information is of particular interest in its possible application[3] for the measurement of the energy as well as the identification of individual charged particles in the relativistic region.

The present investigation was carried out by using a stack of thin metal foils, uniformly spaced and sealed in a vacuum vessel. The stack was placed in the test beam of the Brookhaven alternating-gradient synchrotron (AGS) where pions and protons in the momentum region of from 0.8 to 3.5 BeV/c are available. The particle beam was incident on the foils at an angle of 60° from the normal to the surfaces. A specially designed light funnel[5] collects the radiation in the forward direction to a photomultiplier, type 56AVP with $S11$ response, and a similar funnel collects the backward radiation into a second photomultiplier. Both the light funnels and the photomultipliers were also enclosed in the same vacuum vessel so as to ensure the elimination of any effect due to Cherenkov radiation in the system. Particle selection was accomplished by a gas Cherenkov detector in anticoincidence with a beam-defining triple-counter telescope. Because of the extremely low intensity of the radiation under investigation, single photons had to be detected. The photomultipliers and the associated electronic system were adjusted and calibrated with an artificial light source so as to give the best single photoelectron detection. The signals from both the forward and backward photomultipliers were gated by the particle-defining telescope and stored in two separate pulse-height analyzers.

Figure 1 illustrates the experimental setup with a cross-section sketch of the transition-radiation detector and a block diagram of the electronics system used. The metal foils employed here were steel foils, 1 mil thick, coated with a layer of evaporated aluminum which is only a few tenths of a micron thick. The aluminum coating served primarily as a light reflector. The number of foils used varied

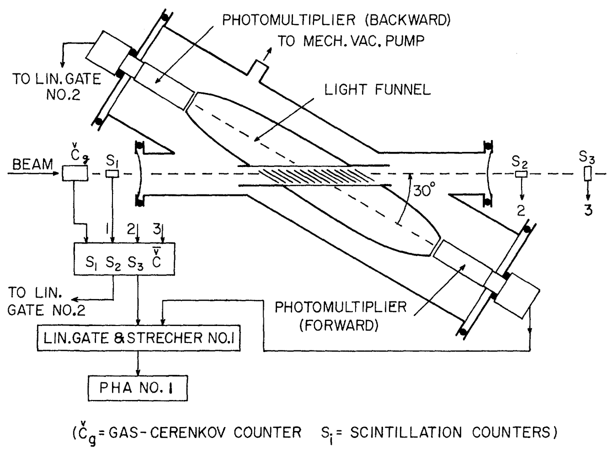

FIG. 1. Sketch of the experimental setup and block diagram of the electronics.

from 12 to 235, spaced uniformly to give a total traversal length of 8 in.

Although the intensity of the radiation from this stack increases with the number of foils, the transmission of radiation by multiple reflection between the foils annuls this gain above a certain number of foils. An optimum number was found for the present arrangement, amounting to 116 foils, and this number was adopted as the standard for all subsequent measurements.

As mentioned above, the transition radiation system was completely enclosed in a vacuum so as to eliminate any possible effect due to Cherenkov radiation. There are, however, other possible background effects due to scattered particles, δ rays, etc. This background was measured in three different ways: (i) By replacing the foils with the same thickness of solid material; this simulated the interactions in the foils, but without presenting the multitude of interfaces. (ii) By masking the photomultipliers with black paper; this prevented light from reaching the photocathode, but still allowed spurious effects due to δ rays or other interaction products to reach the photomultiplier. (iii) By delaying the signal with respect to the gate of the particle defining counter telescope; this accounted for the chance coincidences.

The three different backgrounds measured were all small compared to the main effects for the low-energy protons. For all the data presented here, the background measured in (i) has been used, as being the most appropriate.

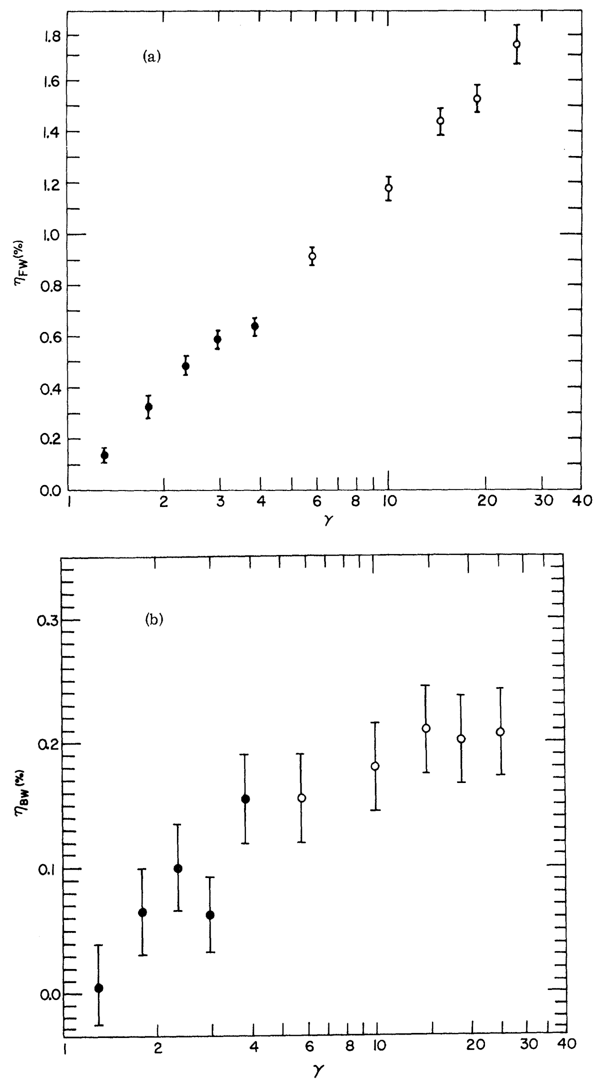

FIG. 2. Efficiency η for detecting transition radiation as a function of $\gamma = E/m_0c^2$. (Note.—Horizontal scale is logarithmic.) (a) In the forward direction. (b) In the backward direction.

The results of the measurements are presented in Figs. 2(a) and 2(b), where the efficiency η for radiation detection, which also represents the intensity of the radiation, is plotted as a function of γ in a logarithm scale [$\gamma = (1-\beta^2)^{-1/2}$, where $\beta = v/c$ and v is the velocity of the particle in question]. These points are the combined results of two independent runs.

Figure 2(a) shows the results of the radiation detected in the forward direction. Open circles indicate the data obtained with pions whereas solid circles indicate those obtained with protons. The results show a logarithmic increase of the intensity of the radiation with γ, regardless of the mass of the particles involved, or with the total energy for a given kind of particle. Repeated runs at different times show a very consistent results. Figure 2(b) shows the detected radiation in the backward direction with similar characteristics in the energy dependence, although the backward intensity is very low (approximately 8 times less than that in the forward direction). The errors indicated in Figs. 2(a) and 2(b) represent the combined errors due to systematic as well as statistical uncertainties.

Direct comparison of the experimental results with theory on the energy dependence is rather involved because of the following factors: (a) The thickness of the aluminum coating is at least comparable to the "zone of formation" of transition radiation in aluminum for the wavelength region investigated. Extensive calculations are necessary to compute the intensity due to the aluminum and that due to the steel. Furthermore, the dielectric properties of steel are not well known. (b) The effect of the variation of the angular distribution of the radiation on the light collection at different momenta is not definitely known. (c) The angle of incidence of the particles is not normal. However, for normal incidence in materials without absorption bands in the optical region, the theoretical prediction for the transition radiation also gives a logarithmic increase in energy dependence.

Similar experimental results have also been obtained using aluminum foils. Experiments with silver foils are in progress and these results will be presented in a more detailed report at a later date.

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