TRANSITION RADIATION OF NONRELATIVISTIC ELECTRONS IN THIN ALUMINUM FILMS

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We have investigated the radiation produced when an electron beam (current 1 - 2 μA) with energy E up to 60 keV passes perpendicular to the surface through thin aluminum films (d = 133 - 329 Å) in the interval of wavelengths λ from 3480 to 5500 Å at angles θ from 0 to 90° relative to the electron motion. The radiation was analyzed with the aid of polarization and interference filters and was detected with a photomultiplier.

The photomultiplier currents due to the light polarized in the radiation plane (plane containing the normal to the film surface and the observation direction) greatly exceed the value of the background made up of fluctuations of the dark current ($\sim 2 \times 10^{-9}$ A). The dark current ($\sim 10^{-8}$ A) was compensated for. For light polarized in the perpendicular plane, the currents were comparable with the background. The photomultiplier currents produced when the working electron beam passed through the thin colloid substrate on which the aluminum was deposited did not exceed the fluctuations of the dark current. Control measurements have shown that the detecting system had no angular and polarization characteristics of its own.

The radiation turned out to be polarized in the radiation plane and its degree of polarization reached 98%. As seen from Fig. 1 (E = 60 keV, d = 329 Å, λ = 4670 Å, θ = 50°, ● and ▲ - data for angles 0 - 90° and 90 - 180°, respectively), the experimental results show a good linear dependence of the radiation intensity on $\sin^2\theta_0$ (θ_0 = angle between the transmission plane of the polarization filter and the radiation plane).

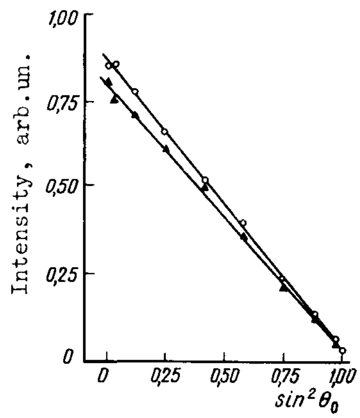

Fig. 1

The polarization obtained agreed fully with that expected from the Ginzburg-Frank theory of transition radiation [1], with which the experimental results will be compared. The theoretical curves were calculated using the formula given in [2] for the transition radiation from a plate. The optical constants used for the calculations were taken from [3].

The absolute intensity of the registered radiation was determined with the aid of the calculated efficiency of the detecting system, since we had no standard lamp for its calibration. The difference between the intensities in the radiation plane and in the plane perpendicular to it were compared with the transition-radiation theory.

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It turned out that the absolute intensity of the observed radiation exceeds its theoretical value by a factor 1.65. The experimental error in the measurement of the radiation intensity did not exceed 8%. Such a disparity between experiment and theory is apparently connected with the uncertainties of some of the quantities entering in the efficiency of the detecting system. This assumption is further supported by the fact that the experimental results obtained for silver and gold films exceed the theoretical values by the same factor. In all subsequent comparisons with theory we shall divide the experimental data by 1.65. The solid curves in all the figures are theoretical.

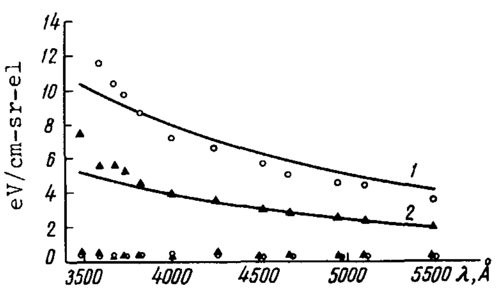

Fig. 2

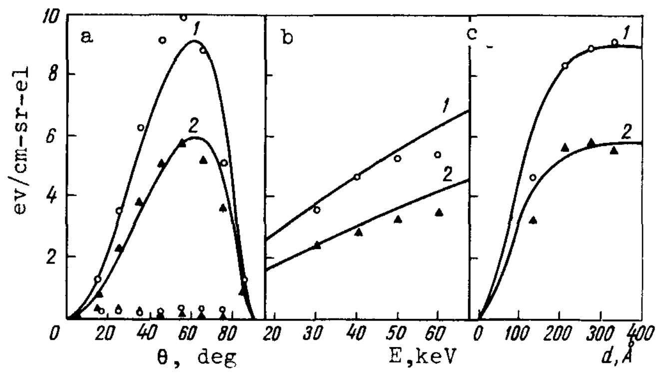

Fig. 3

Figure 2 (E = 60 keV, d = 275 Å, 1 - data for $\theta = 60°$, 2 - data for $\theta = 30°$) shows the spectral distributions of the radiation, and, by way of illustration, the corresponding radiation distributions observed in the perpendicular plane. In the wavelength region from 3800 to 5500 Å the results are in good agreement with theory. In the region from 3480 to 3800 Å experiment shows a much greater spectral dependence for both observation angles.

In Fig. 3a the experimental angular distribution of the radiation is shifted somewhat towards the smaller angles, but on the whole the angular distribution is that expected from theory (E = 60 keV, d = 329 Å. 1 - data for λ = 3730 Å, 2 - for 4670 Å).

In Fig. 3b the experimental results show a linear increase in the radiation energy with increasing electron energy (d = 133 Å, $\theta = 60°$, 1 - data for λ = 3730 Å, 2 - for 4670 Å). Fig. 3c shows the expected dependence on the film thickness (E = 60 keV, $\theta = 60°$, 1 - data for λ = 3730 Å, 2 - for 4670 Å). The film thickness was measured accurate to ~10 Å.

The optical constants of metallic films depend on their thickness and on the preparation technology [4]. The aluminum films used by us were obtained under somewhat different conditions than those whose optical constants were used to calculate the theoretical curves. It is possible that the observed small deviations of the experimental data from the theoretical ones are due to just this fact.

We observed in the measurement that the intensity decreased with the time of electron bomabardment of the film. This decrease in intensity can be seen in Fig. 1 for the data at angles 90 - 180°. This circustance strongly influences freshly prepared films. When these are exposed for a long time, the intensity can decrease to 30%.

It can be concluded that the obtained experimental results on the radiation produced by electrons in thin aluminum films agree on the whole with the theory of transition radiation.

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POSSIBLE EXISTENCE OF A PASSIVE BARYON STATE

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A group of physicists from the Tokyo Institute of Nuclear Research reported at the London Conference of 1965 [1] that they observed an extensive air shower with approximately 10^5 particles, falling at a zenith angle of 86 ± 1/2 deg. This shower was extremely interesting, since it was observed under a layer of atmosphere approximately 12,000 g/cm^2 thick. The authors have shown that this shower, with energy [3-5] 10^{14} eV, accompanies a nuclear interaction occurring under the installation in a layer 200 - 400 g/cm^2 thick.

The authors indicate that an array of area $S = 100$ m^2 and solid angle $\Omega = 1$ will record such events produced by exponentially absorbed nucleons once every 10^{36} years. Showers due to bremsstrahlung of muons should be registered once every 10^5 years. One can likewise not exclude the possibility of interpreting such an event as being a nuclear interaction between muons of energy $\sim 5 \times 10^{14}$ eV, but then the estimated observation frequency is at best once every 10 years, whereas the duration of the experiment was only 3500 hours.

The experimental situation becomes quite natural if one admits of the possibility that the nucleon goes over into a passive state after the interaction [2]. It is easy to calculate the angular distribution of the nucleons from this point of view. By considering a flux of particles traveling in the atmosphere at a zenith angle ϑ, we can, neglecting the fluctuations of the inelasticity coefficient K for the interaction of the first-generation nucleons with flux N_1, write equations for the variation with depth (x) of the flux S_1 of first-generation baryons and the flux N_2 of second-generation nucleons

$$\frac{\partial^2 S_1}{\partial x \partial E}(E, x, \vartheta) = \frac{1}{1-K}\frac{\partial N_1}{\partial E}\left(\frac{E}{1-K}, 0\right)e^{-x} - \frac{\partial S_1}{\partial E}(E, x, \vartheta)\frac{\beta}{x}, \quad (1)$$

$$\frac{\partial^2 N_2}{\partial x \partial E}(E, x, \vartheta) = \frac{\partial S_1}{\partial E}(E, x, \vartheta)\frac{\beta}{x} - \frac{\partial N_2}{\partial E}(E, x, \vartheta), \quad (2)$$

where

$$\beta = 1/\rho_0 c\tau_0 \cos\vartheta (E/Mc^2). \quad (3)$$