Influence of the Medium on the Emission of Relativistic Electrons

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We compare the experimental data on the emission of 0.25–3.7 GeV electrons in periodic layered media and in individual plates with various theories. It is shown that the experimental data agree well with the theory of resonant emission when account is taken of the influence of multiple scattering of the electrons in the layered medium.

THE results of experiments on relativistic muons and electrons in periodic layered media and in individual plates have already been reported in[1-6]. We present here the latest experimental data and compare the experimental results with various theories.

We investigated the emission of electrons in layered media of various types. Each medium contains n layers of dense matter of thickness l_1 each, located in air and equally spaced αl_1 apart. The dense matter was paper or organic film. Background measurements were made for each medium, by replacing the layered medium with a single plate of thickness equivalent to that of the matter in the layered medium. The difference between the number of quanta emitted by a particle in the layered medium and in the equivalent plate was identified with the resonant (or transition) radiation; there are no bremsstrahlung photons in this difference.

Figures 1 and 2 show, for different layered media, the emission spectra in the x-ray part of the spectrum of electrons having different energies, referred to a

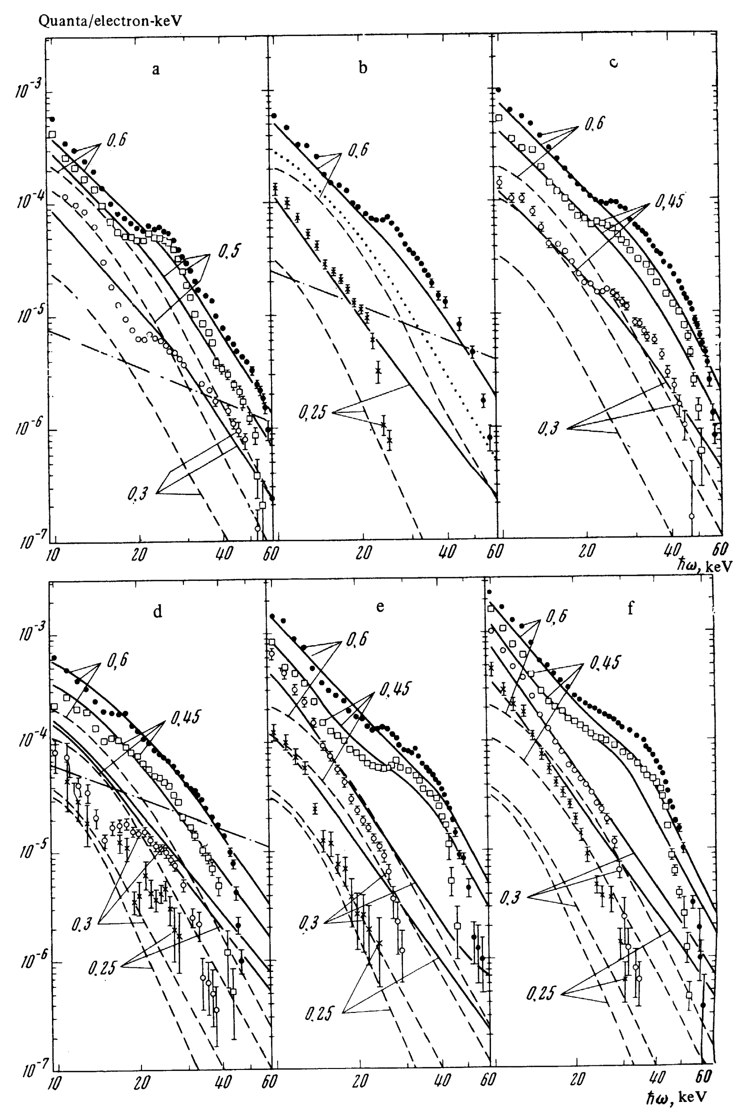

FIG. 1. Differential emission spectra of electrons with energy (0.25–0.6) GeV (numbers on the curves) in a paper-air layered medium, referred to a single period: a) $l_1 = 2.83 \times 10^{-3}$ cm, $\alpha = 18.8$, n = 1050; b) $l_1 = 9.3 \times 10^{-3}$ cm, $\alpha = 5.84$, n = 780; c) $l_1 = 9.3 \times 10^{-3}$ cm, $\alpha = 11.6$, n = 780; d) $l_1 = 2.43 \times 10^{-2}$ cm, $\alpha = 3.0$, n = 300; e) $l_1 = 2.43 \times 10^{-2}$ cm, $\alpha = 6.59$, n = 300; f) $l_1 = 2.43 \times 10^{-2}$ cm, $\alpha = 11.1$, n = 300. Dashed curves–R, T, and TP theories; solid curves–RSI, dotted curves –RS; dash-dot curves–bremsstrahlung theory for the case of an isolated atom.

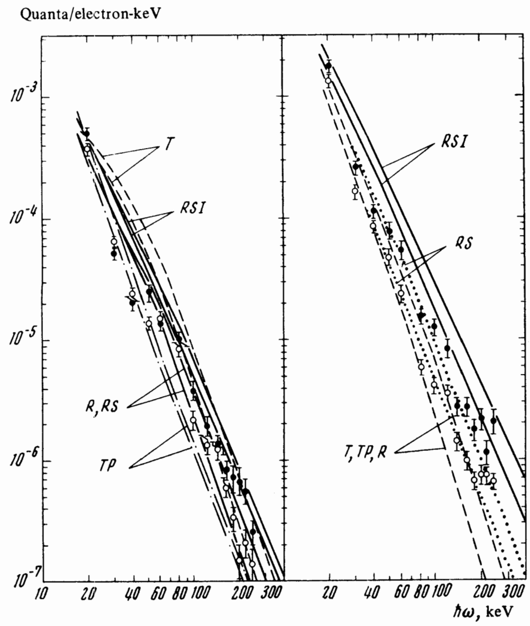

FIG. 2. Differential emission spectra of electrons of energy 2.8 (●) and 3.7 GeV (○), referred to a single layer of the layered media of Figs. 1a and 1f. For like curves, the lower ones corresponds to 2.8 GeV and the upper to 3.7 GeV.

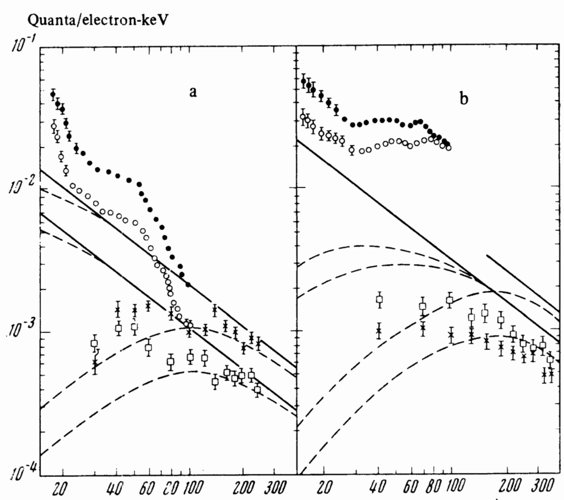

FIG. 3. Differential spectra of electron emission in individual plates a) Organic glass, l_1 = 7.3 cm: ○ = 0.25 GeV, × = 2.8 GeV; l_1 = 3 cm: ● = 0.25 GeV, □ = 2.8 GeV. b) Aluminum, l_1 = 1.1 cm: ●—0.45 GeV, ○—0.6 GeV, ×—2.8 GeV; l_1 = 2.2 cm: □ = 2.8 GeV. Solid curves—bremsstrahlung theory for the case of an isolated atom; dashed curves—bremsstrahlung theory with allowance for the density effect.

single period (or to a single layer). The experimental spectra are compared with the expected ones calculated by using the formulas of the resonant radiation (R[7,8]) transition radiation (T[9]. The limiting case of the Ginzburg-Frank formula[10] for relativistic particles and frequencies higher than optical ones), transition radiation for a single plate (TP[9]), and resonant radiation with allowance for the multiple scattering of the electrons in the layered medium (RS and RSI[11] for the case of small and large density drops of the matter in the layered medium, respectively; the RS curves in Fig. 1b and the bremsstrahlung curves in Figs. 1a, b, c are shown by way of illustration). For the data of Fig. 1, the theories of resonant (R) and transition (T, TP) radiation give the same result (dashed curves). This means that the interference of the transition radiation from different boundaries of the layered medium is negligible and the data should contain only radiation on the two boundaries of the layer, and should not depend on the layer thickness. In addition, according to the theory, the radiation intensity should not depend on the intervals between the layers. The absolute value of the measured radiation yield, however, exceeds in the main the theoretically predicted yield. The disparity between the experimental and the theoretical data depends on the parameters of the medium and on the energies of the electron and photon. For media made up of thin layers, this disparity is small (Fig. 1a): in the case of thick layers, the experimental radiation yield exceeds the expected one by more than one order of magnitude (Fig. 1f). The experimental radiation yield increases with increasing layer thickness and with increasing gaps between layers.

All the experimentally observed peculiarities are contained in the formulas for resonant radiation, if allowance is made for multiple scattering. The experimental data agree well with the results of this theory (RSI) both in absolute magnitude and in the functional relations. This additional radiation, which is many times larger than the transition radiation and the usual (Bethe-Heitler) bremsstrahlung taken together, is interpreted as interference bremsstrahlung of electrons in a layered medium, and is due to the presence of the boundaries[11]. In the case of very strong scattering, when the latter causes complete disarray of the interference, this additional radiation should decrease.

For high-energy electrons, when the coherent radiation length becomes comparable with the period of the medium, interference sets in between the radiation from different boundaries, and the different theories give different results. In this case, allowance for multiple scattering leads to a smaller change of the resonant-radiation curves; in addition, this theory is valid only for photons of the high-energy end of the spectrum ($\hbar\omega \gtrsim 100$ keV)[11].

Taking the foregoing into account, we can conclude that the experimental data agree well, on the whole, with the results of the theory of resonant radiation when account is taken of the influence of multiple scattering, i.e., interference effects take place and the experimental results cannot be explained by a theory in which it is assumed that independent summation of the transition radiation from the boundaries of the layered medium takes place. We note in this connection that Garibyan's statement[9] that the influence of multiple scattering becomes manifest in the investigated media only for electrons with energy higher than ~11 GeV has no bearing whatever on a layered medium, and his conclusions are valid only for the case of one interface between media.

Figure 3 shows the measured electron emission spectra for individual bulky plates of organic glass and aluminum. In such plates, the transition radiation from the boundaries is negligibly small, and only bremsstrahlung is produced. The data indicate that the radiation is significantly suppressed ($\sim E^{-2}$) with increasing electron energy. This agrees well with the deductions of Ter-Milaelyan's theory[12] concerning the influence of the polarization of the medium on the bremsstrahlung (the density effect). On the other hand, in the energy region 0.25—0.6 GeV the experimental radiation yield exceeds the expected value by several times, a fact more pronounced in the case of aluminum. For organic glass, the experimental yield in the ~100 keV region is comparable with the expected Bethe-Heitler value.

The bremsstrahlung formulas for an unbounded medium cannot explain the observed effect, which is connected with the presence of boundaries at the plate and the appreciable scattering of the electrons in it; the additional radiation has in this case the same character as in a layered medium, but we have no corresponding theory to compare with. Pafomov[13] has calculated the bremsstrahlung for plates, but a quantitative analysis of these formulas is so cumbersome that it is difficult to perform it even with the aid of a computer.

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