BREMSSTRAHLUNG SPECTRUM OF A FAST ELECTRON IN A SINGLE CRYSTAL

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1. The bremsstrahlung of a high-energy electron is a process that takes place in an effective region having a large longitudinal dimension $\ell \equiv [E(E - \omega)/m^2\omega]$ and transverse dimensions $\sim m^{-1}$. The single-crystal atoms lying within this region take part in the process coherently, and the radiation intensity per unit path is proportional to the number of atoms in the effective region. This leads to a dependence of the energy spectrum of the bremsstrahlung on the angle of entry of the particle into the single crystal [1-3]. The maximum radiation corresponds to entry angles that are multiples of a/ℓ. A quantitative estimate of this effect was obtained by Ter-Mikaelyan [3], who pointed out that its existence requires that the rms scattering angle in the entire crystal be smaller than the rms angle of the first maximum.

It has been customary, in considering the interference effect in the bremsstrahlung spectrum in a single crystal, to disregard the fact that the large effective radiation length can lead to a suppression of the radiation, owing to the scattering of the electron in the effective region. A similar effect was indicated for an amorphous medium in [4]. The influence of the scattering will be appreciable if a mean-square scattering angle comparable with $(m/E)^2$ is acquired over the effective length. A distinguishing freature of the crystal is the quadratic dependence of the square of the scattering angle on the length. Taking the foregoing into account, we can write for the condition of suppressing the radiation by scattering in the effective region

$$E_s^2\ell^2/E^2aL_{rad} > m^2/E^2, \quad (1)$$

where a is the lattice constant, $E_s = m_e(4\pi/e^2)^{1\,2}$, and

$$L_{rad} = n_0Z^2e^6m^{-2}\,4\,\ln(191Z^{-1/3}).$$

Comparing this inequality with the condition indicated above for the existence of the interference effect, we find that, starting with energies higher than

$$E_1 \approx m^{2/3}E_s^{1/3}(L_{rad}/a)^{1/6} \quad (2)$$

the scattering in the effective region alters greatly the bremsstrahlung spectrum in the single crystal. The radiation frequency should satisfy the condition

$$\omega ma >> E, \quad (3)$$

and the crystal thickness L should lie in the region

$$(E^2/m^2\omega) << L < Ea^2. \quad (4)$$

2. A quantitative estimate of the suppression of the bremsstrahlung in the single crystal by scattering in the effective region is best obtained in analogy with the analysis of the influence of scattering on bremsstrahlung in an amorphous region [5]. We confine ourselves for simplicity to an entry angle $\theta_0 = a/\ell$ corresponding to the first maximum. In the limiting case

$$E_s E^2 m^{-3}(aL_{rad})^{-1/2} << \omega << E \quad (5)$$

we can disregard scattering in the effective region, and the radiation spectrum takes the form

$$\frac{1}{T}\frac{dE}{d\omega} = \frac{e^2}{\pi}\frac{E^2 E_s^2}{m^4 a L_{\mathrm{rad}}}\frac{1}{\omega}. \qquad (6)$$

In the opposite limiting case

$$\omega << E_s E^2 m^{-3} (a L_{\mathrm{rad}})^{-1/2} \qquad (7)$$

the radiation spectrum changes noticeably:

$$\frac{1}{T}\frac{dE}{d\omega} = \frac{2e^2}{\sqrt{3}\pi} E^{2/3} (E_s^2\, 3 a L_{\mathrm{rad}})^{-1/3} \omega^{1/3}. \qquad (8)$$

It is interesting to note that for entry directions corresponding to the minimum radiation, the intensity remains unchanged, owing to the small number of atoms in the effective region; at the same time, for an entry angle corresponding to maximum radiation, the radiation intensity is noticeably decreased by the scattering. The effect under consideration thus leads to a smoothing of the interference character of the spectrum.

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QUANTUM ELECTRODYNAMICS WITH TWO FERMIONS. II

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It was shown in an earlier paper [1] that in quantum electrodynamics with two fermions (electron and muon), diverging diagrams containing closed loop can cancel each other, and it is then possible to construct a theory free of infinite renormalizations. The proposed modification of the theory met with sharp criticism, since reversal of the sign of the loop reverses also the sign of its imaginary part, which is incompatible with the physical requirements of unitarity. An attempt was made in [1] to get around this objection by using the fact that the imaginary part of the muon loop is smaller than that of the electron loop at all values of photon momentum. But this does not get rid of the objections, since it contradicts the analyticity conditions as applied to individual vertices of the loop. In addition, if a closed muon line has four vertices, then it is connected with the probability of the radiative deceleration and is therefore positive-definite.

We shall attempt here to modify the procedure proposed in [1] in a way as to retain the main result, but avoid any contradiction to the general requirements of field theory. We shall