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SCATTERING OF LIGHT BY LIGHT

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Scattering of light by light is a fundamental effect in quantum electrodynamics. This process has been investigated so far principally within the framework of quantum electrodynamics without allowance for strong interactions [1, 2]. In [3] they considered resonant scattering of light by light via single-particle hadron states (π^0, η^0, etc.). Such scattering is significant only in narrow energy intervals corresponding to the positions of the intermediate-meson masses.

It is of great interest to investigate the contributions of two-particle hadronic states to the process of scattering of light by light (e.g., $\pi\pi$ and $K\bar{K}$ states). The expressions obtained in [4] for the amplitudes of the reaction $\gamma + \gamma \to \pi + \pi$ have enabled us to calculate the s and d waves of scattering of light by light with the aid of the method of dispersion relations. The imaginary part of the amplitude of the process $\gamma\gamma \to \gamma\gamma$ was expressed with the aid of the unitarity condition in terms of the amplitude of the process $\gamma\gamma \to \pi\pi$, and the real part was reconstructed with the aid of the imaginary part from the dispersion equation with one subtraction. The calculations were performed for white light. The cross section of the s waves of $\gamma\gamma \to \gamma\gamma$, corresponding to "down" and "down-up" s waves of the process $\gamma\gamma \to \pi\pi$ [4], are shown in Fig. 1 (the cross sections of the d waves are smaller than the cross sections of the s waves at the threshold and are comparable with them in the region of the f meson). Comparing the obtained curves with the results of [1, 2], we can see that scattering of light by light via a two-pion state dominates in a wide range of energies (approximately from 300 to 900 MeV). We have calculated the amplitudes of the process $\gamma\gamma \to K\bar{K}$ and their contribution to the process $\gamma\gamma \to \gamma\gamma$. In the energy region under consideration, the contribution of the $K\bar{K}$ two-particle state to the process $\gamma\gamma \to \gamma\gamma$ is negligibly small. The cross section for the scattering of light by light $\gamma\gamma \to \gamma\gamma$ is shown qualitatively in Fig. 2.

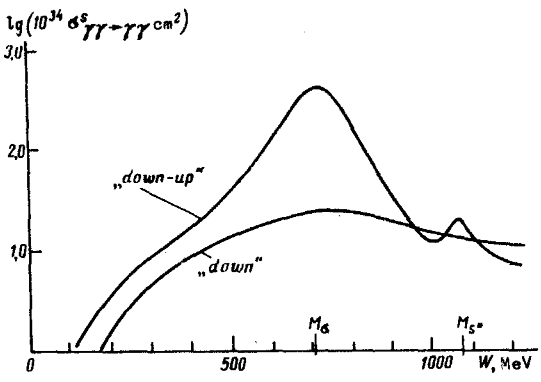

Fig. 1

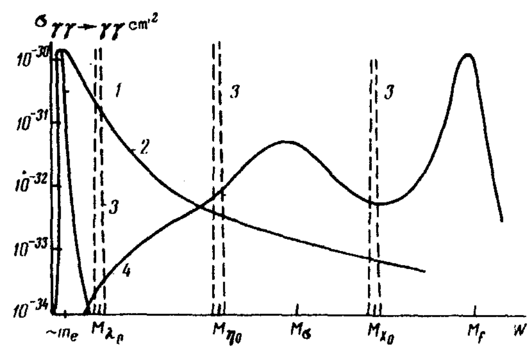

Fig. 2. 1 - $4\pi(d\sigma_{\gamma\gamma}/d\Omega)$ (W, $\theta \simeq \pi/2$), 2 - $4\pi(d\sigma_{\gamma\gamma}/d\Omega)$ (W, $\theta = 0$) [1]; 3 - resonant scattering of light [3]; 4 - scattering via two-pion state ($\sigma^s_{\text{down-up}} + \sigma^d$).

Let us consider further the process ee $\to$ ee$\gamma\gamma$, production of two γ quanta in colliding beams. It can proceed either as double bremsstrahlung or via the $\gamma\gamma \to \gamma\gamma$ process (Fig. 3). The double-bremsstrahlung cross section is given in [5]. Let us compare the cross section obtained in [5] with the cross section obtained in the present paper for the reaction ee $\to$ ee$\gamma\gamma$ with a two-photon interaction mechanism (see Fig. 3).

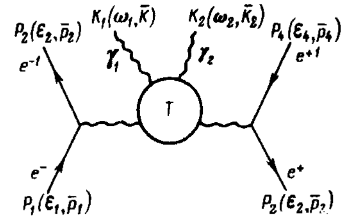

Fig. 3

We choose the kinematic conditions to be symmetrical and such that the "masses" of the intermediate virtual photons are small in comparison with their energies (forward scattering of the leptons). In this case we can factorize the lepton vertices in the amplitude of the process ee $\to$ ee$\gamma\gamma$ and connect the differential cross section of this process with the cross section for the scattering of light by light (see [6]):

$$\frac{d\sigma_{ee\to ee\gamma\gamma}}{d\omega_1 d\Omega_1 d\omega_2 d\Omega_2 d\Omega_e} = \frac{d\sigma_{\gamma\gamma\to\gamma\gamma}}{d\Omega_1}\left(\frac{e^2}{(2\pi)^3}\right)^2 \frac{\omega^4}{E^2(p_1-p_3)^2(p_2-p_4)^2}. \tag{1}$$

Let us compare (1) with the double-bremsstrahlung cross section in the case when $m_e \ll \omega = \omega_1 = \omega_2 \ll E = \varepsilon_1 = \varepsilon_2$. To this end we rewrite the double-bremsstrahlung cross section in the form

$$\frac{d\tilde{\sigma}}{d\omega_1 d\Omega_1 d\omega_2 d\Omega_2 d\Omega_e} = \frac{e^8}{32(2\pi)^8}\,\frac{1}{E^2\omega^2}\,\frac{\left(3 + \dfrac{2\sin^2\theta}{(1-\cos\theta)^2}\right)}{(1-\cos\theta)^2}. \tag{2}$$

Here θ is the angle of the scattering of the γ quanta relative to the initial colliding beams. In forward lepton scattering the energy of the intermediate virtual photons can be varied from zero to

$$\omega_{max} = E\left(\left(\frac{\alpha^2}{4}+\alpha\right)^{1/2} - \frac{\alpha}{2}\right),$$

which at a given colliding-beam particle energy is determined by the values of the photon masses $m_\gamma^2 = \alpha m_e^2 = |(p_1 - p_3)^2| = |(p_2 - p_4)^2|$, i.e., if $m_\gamma^2 = E(E - \omega) - [(E^2 - m_e^2)((E-\omega)^2 - m_e^2)]^{1/2} - 2m_e^2 \leq \alpha m_e^2$, then $\omega \leq \omega_{max}$. For comparative estimates of the cross sections (1) and (2), we shall use the curves of Fig. 1. Let E = 2.5 GeV, $\omega \sim 500$ MeV, $\theta \geq 8 - 10°$ (the photons are produced at sufficiently large angles), and $\alpha \sim 10$. We assume that $\sigma_{\gamma\gamma\to\gamma\gamma} > 10^{-33}$ cm^2 in the considered region of photon energies. Under these assumptions, the cross section (1) is large in comparison with the double-bremsstrahlung cross section (2):

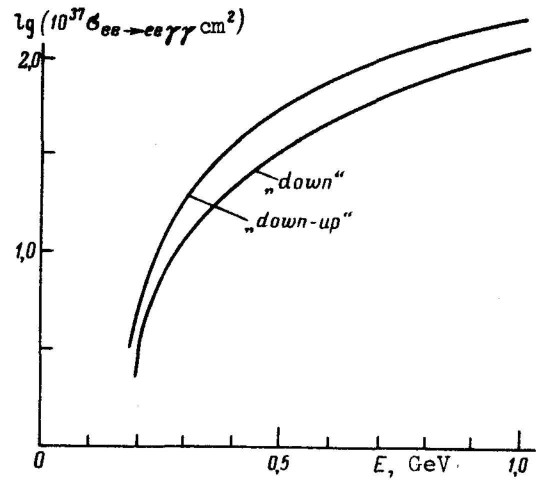

Fig. 4

$$\frac{\text{cross section (2)}}{\text{cross section (1)}} \lesssim 1\%.$$

Thus, by recording photons with specified energies at sufficiently large angles ($\theta \geq 8 - 10°$), and simultaneously recording the forward scattering of one of the leptons, we can separate the process $ee \to ee\gamma\gamma$ with intermediate two-photon interaction. From the known kinematic relation (1) we can obtain in such a case the cross section for the scattering of light by light.

We note that the $ee \to ee\gamma\gamma$ processes were observed experimentally [7], but with photon production along the direction of the initial beams. Figure 4 shows the cross sections of the processes $ee \to ee\gamma\gamma$, calculated from the s waves of scattering of light by light (Fig. 1) with the aid of the equivalent-photon method. The cross sections of the reaction $ee \to ee\gamma\gamma$ are quite small and lie at the borderline of the present-day experimental capabilities.

In conclusion, we are deeply grateful to N.N. Bogolyubov for interest in the work and valuable hints, and to D.V. Shirkov and R.M. Muradyan for a discussion of the results.

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ANOMALOUS ABSORPTION OF ELECTROMAGNETIC RADIATION AT DOUBLE THE PLASMA FREQUENCY

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The possibility of anomalous absorption of energy of a high-frequency electric field

$$E_z(x,t) = E_0 \cos(\omega_0 t - k_0 x) \tag{1}$$

is most frequently attributed to the decay of the pump wave into a plasmon and a phonon near the critical density of the plasma n_c [1 - 4]. We wish to call attention in this note to the fact that in a hot plasma it is necessary to take into account the presence of one more absorption band at densities one-quarter the critical value. This absorption is due to the process of the decay of the pump wave into two plasma oscillations (ω_1, $\vec{k}_1$) and (ω_2, $\vec{k}_2$). The instability increment can be expressed in terms of the interaction matrix $V_{k_1,k_0,-k_2}$ [5], which connects the probability amplitudes of the three waves:

$$\nu_d(k) = \sqrt{\left(V_{k_1,k_0,-k_2}\right)^2 \frac{E_0^2}{8\pi|\omega_0|} - \frac{1}{4}(\omega_0 - \omega_1 - \omega_2)^2}. \tag{2}$$

Here the matrix element $V_{k_1,k_0,-k_2}$ differs from the element $V_{k_0k_1k_2}$ calculated