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THE SCATTERING OF LIGHT BY LIGHT

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It is well known that in classical electrodynamics as a direct consequence of the linearity of Maxwell's equations, waves propagate independently of one another. Quantum effects of the interaction of electromagnetic waves with the vacuum electron-positron field lead to the nonlinear effect of photon-photon scattering. The theoretical problem of the scattering of light by light has been solved in a number of papers.[1-3] A number of attempts were made to observe the effect experimentally.[4] There has, however, been no success in discovering the scattering of light by light: this is explained by the extremely small value of the cross section for such a process.

In the range of frequencies $\omega \ll m$ (m is the electron mass) a quantum electrodynamic calculation gives for the value of the cross section, in the center of mass system,

$$d\sigma = \frac{1}{(2\pi)^2}\frac{139}{90^2}\alpha^4\frac{1}{m^2}\left(\frac{\omega}{m}\right)^6(3+\cos^2\theta_0)^2\,d\Omega, \qquad (1)$$

where $\alpha = 1/137$ and θ_0 is the scattering angle ($\hbar = c = 1$). It is easy to see that in the optical range of frequencies the cross section has an insignificant value ($\approx 10^{-64}$ cm^2) and therefore, despite the existence of powerful sources of optical photons, experimental observation of the scattering of light by light in this range of frequencies is extremely difficult.[5]

Because the cross section increases sharply with increasing frequency, it appears hopeful that this interesting process might be observed experimentally at high frequencies. In particular, the cross section attains a value $\sigma \approx 10^{-35}$ cm^2 for $\omega \approx 10^5$ eV. Such frequencies can be realized when γ quanta with energies of several BeV are scattered by optical photons, a preferable source of which can be modern optical quantum generators.

If the energies of the colliding photons in the laboratory system are ω_1 and ω_2, where $\omega_1 \gg \omega_2$, the photon-photon scattering cross section integrated with respect to the scattered photons up to some value ω_3 will be

$$\sigma = \frac{16}{\pi}\frac{139}{90^2}\alpha^4\frac{1}{m^2}\frac{\omega_1^3\omega_2^3}{m^6}\frac{\omega_3}{\omega_1}. \qquad (2)$$

For $\omega_1 = 6\times 10^9$ eV and $\omega_2 = 1.78$ eV (the photon energy of a ruby laser) the cross section will be

$$\sigma = 2.56\cdot 10^{-35}\,\omega_3/\omega_1,\ \text{cm}^2. \qquad (3)$$

The frequency of the scattered photon is given in terms of the scattering angle in the laboratory system by:

$$\omega_3 = \frac{2\omega_1\omega_2}{(\omega_1+\omega_2)-(\omega_1-\omega_2)\cos\theta}. \qquad (4)$$

It follows from (3) and (4) that the principal contribution to the cross section is provided by scattered photons with large energies, where these photons are scattered mainly inside very small angles relative to the direction of the photon with energy ω_1. For example, when scattered photons with energies up to $\omega_3 = 500$ MeV are recorded, the cross section is $\sigma = 2.1\times 10^{-36}$ cm^2. The angle within which the scattered photons are emitted increases with diminishing energy, and is 1.2×10^{-4} for $\omega_3 = 500$ MeV.

We estimate the number of recorded events which can be obtained when beams of γ quanta from modern high energy electron accelerators and the most intense beams of laser photons are used. If γ quanta with energies $\omega_1 = 5$—6 BeV are used, created by electrons with 6 BeV energy (the number of electrons in a pulse of length 10^{-6} sec is 10^{11}; the cross section of the electron beam is 0.03 cm^2), and photons generated by a ruby laser with 500 joules energy[6] with a flash length of 10^{-6} sec are used (the number of photons in the laser flash will be 2×10^{21}), then the frequency of recorded events when the laser is worked with a frequency of 1 cps will be approximately 2—3 per day when recording γ quanta with energies up to $\omega_3 = 500$ MeV. We note that the cross section of the beams of colliding photons was chosen here to be 1 mm^2, which is necessary to separate the scattered photons from the photons of the primary beam with the same energy.

For a 40-BeV electron accelerator (Stanford) the number of electrons in the pulse (planned) is 6×10^{12}. Scattering of γ quanta with energies 33—40 BeV generated by these electrons by the photon beam of the laser considered above yields 10—15 separate photons with energies up to 500 MeV recorded in 1 hour.

The estimates show that the frequency of observing events in the two examples given above exceeds possible noise. One should also bear in mind that a number of possibilities exists for increasing the number of recorded events: increasing the intensity of the laser radiation or the frequency of laser operation, increasing the upper limit of the energy of recorded scattered γ quanta, etc.

Thus we arrive at the conclusion that the discovery and study of the very rare and extremely important process of scattering of light by light is possible when modern intensities of photons from laser radiation and of γ quanta from bremsstrahlung generated by high energy electron bemas are used.

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POLARIZATION IN pp *SCATTERING AT* 8.5 BeV

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WE report here the results of the first measurements of the polarization in pp scattering, carried out with the Joint Institute for Nuclear Research proton synchrotron.

The experimental setup has been placed directly underneath a straight section chamber of the accelerator (Fig. 1). Recoil protons of an energy E_1 scattered at an angle θ_1 on a polyethylene target (with dimensions 0.4 cm $\times$ 0.4 cm in the scattering plane) pass through a window (0.3 mm of steel) and are detected by a telescope S_{123} consisting of three scintillators (0.8 g/cm^2 each) with FU-33 photomultipliers. The scintillator S_3, shielded by graphite plates F_1, F_2 (5.4 g/cm^2) serves as a second target. After the second scattering the protons are slowed down in copper absorbers of varying thickness (F_3, F_3'). The thicknesses of F_3 and F_3' are chosen depending on the angle θ_1 and the beam energy E_0 in such a way that elastic protons, doubly scattered on the hydrogen nuclei in the target and on the C^{12} nuclei, would stop in the scintillators S_4, S_4' (1 g/cm^2) or in the thin copper absorbers F_4, F_4' (0.5 g/cm^2) behind them.

The selection of elastically scattered protons is assured on one hand by the requirement that the light pulses produced in S_4 and S_4' be roughly 15 times greater than the pulse from a relativistic

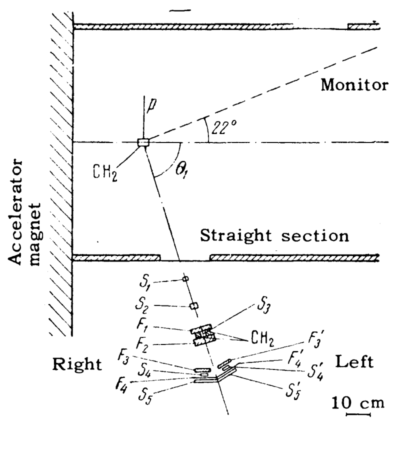

FIG. 1. Diagram of the array