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INCOHERENT SCATTERING OF HIGH-ENERGY PHOTONS ON NUCLEI

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НЕКОГЕРЕНТНОЕ РАССЕЯНИЕ ФОТОНОВ ВЫСОКОЙ ЭНЕРГИИ НА ЯДРАХ

Рассмотрен некогерентный комптон-эффект на ядрах. Исследование этого процесса при высоких энергиях позволяет получить полезную информацию о механизме взаимо-

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ABSTRACT

The incoherent scattering of high-energy photons on nuclei is considered in the framework of the multiple scattering theory. It is shown that the investigation of the A-dependence of differential cross sections of this process can provide with interesting information on the mechanism of high-energy photon-nucleus interaction.

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The high-energy photon-nuclei interaction processes enable one to get interesting information for elementary-particle physics. For example, the total cross sections for unstable vector meson-nucleon interaction were found from the experiments on the vector meson photoproduction on nuclei. The study of such processes permits to consider the problems connected with the vector dominance model [1] and with the possibility of photon transitions into the many-particle hadron states [2].

The theory is known to predict for the A-dependence of the total cross sections of the photoabsorbtion on nuclei $\sigma(\gamma A)$ to transform from the linearity at low energies $(\Delta \ell \gg 1$, $\Delta = \frac{m_2^2 - m_1^2}{2k}$ – the minimal longitudinal momentum transfer in the reaction $1+N \to 2+N$, $\ell = \frac{1}{\sigma \rho_0}$ – the mean free path of the hadron in nucleus) to the law $A^{2/3}$ at high energies $(\Delta \ell \ll 1)$

The experiments [3] performed in the recent years to verify this prediction show, that photons when interacting with nucleus behave to a certain extent as hadrons (vector mesons) for which shadowing corrections are essential. However, the predicted evolution in A-dependence of $\sigma(\gamma A)$ was not observed, and up to 18 GeV the experiments gave for this dependence the form $A^{0.9}$. To explain this fact some hypotheses were suggested [2-5]; however, the experiments at higher energy and the further study of interaction processes of photons with matter seem to be necessary for a final answer.

In this light the study of incoherent photon scattering on nuclei at high energy and large momentum transfer seems to be important.

Besides the direct process of elastic scattering of photons, we consider contributions from discreet intermediate channals which are due to the photoproduction of vector mesons ρ^0 and ω on a single nucleon with their subsequent transition into photon. (We neglet the contribution from φ - meson).

Using the closure and the standard technique for a calculation of differential cross sections of incoherent processes [6], one can obtain expressions for a cross section of the process $\gamma A \to \gamma A'$ we are interested in, in the limits of low $(\Delta l \gg 1)$ and high $(\Delta l \ll 1)$ energies.

At low energies $(E_\gamma \lesssim 3$ GeV) the condition $\Delta l \gg 1$ enables us to neglet the contributions from interference, and as a result the incoherent cross section of the process in question takes the form:

$$\frac{d\sigma^{Inc}}{dt} = A\frac{d\sigma_{\gamma\gamma}}{dt} + \frac{1}{4\pi}\int e^{i\vec{q}\vec{\beta}} d^2\beta \left[\Omega_{\gamma\rho,\gamma\rho}(\vec{\beta}) + \Omega^2_{\gamma\omega,\gamma\omega}(\vec{\beta}) + 2\Omega^2_{\gamma\rho,\gamma\omega}(\vec{\beta})\right] \times \frac{A - N(0,\tilde{\sigma})}{\tilde{\sigma}} \quad (1)$$

In this expression $\frac{d\sigma_{\gamma\gamma}}{dt}$ is the differential cross section of the Compton-effect on a nucleon,

$\Omega_{\gamma x,\gamma y}(\vec{\beta}) = \int \frac{d^2\Delta}{k^2} e^{i\vec{\Delta}\vec{\beta}} f_{\gamma x}(\vec{\Delta}) f^*_{\gamma y}(\vec{\Delta})$; $\quad x, y = \rho, \omega$,

$\tilde{\sigma} = \sigma - \Omega_{\rho\rho,\rho\rho}(\vec{\beta})$ where $\sigma \equiv \sigma^{tot}(\rho N)$ is the total cross section of the ρ^0-nucleon interaction; $f_{\gamma x}(\vec{\Delta})$ is the amplitude of vector meson photoproduction on a nucleon and $N(0,\tilde{\sigma}) = \int d^2 b \frac{1 - e^{-\tilde{\sigma}\int \rho(\vec{b},z)dz}}{\tilde{\sigma}}$ are the "effective nucleon numbers"; $\rho(\vec{b}, z)$ represents the nucleon density function in the nucleus.

Expression (1) is valid for intermediate and heavy nuclei, assuming the equality of elastic amplitudes $f(\rho N \to \rho N) = f(\omega N \to \omega N)$ that follows from quark models. Note, that expression (1) involves effects from all possible ρ^0-and ω-mesons rescatterings with the change of their direction of motion which one must take into account at large momentum transfers.

Now let us assume that the slopes in ρ -and ω -photoproduction amplitudes are the same and equal to that for $\rho - N$ elastic scattering. Introducing the quantity $W = \frac{f^2_{\gamma\rho}(0) + f^2_{\gamma\omega}(0)}{f_{\gamma\gamma}(0)\, f_{\rho\rho}(0)}$ (if the vector dominance model is valid, W=1), we can rewrite expression (1) in the form

$$\frac{d\sigma_L}{dt} = A\frac{d\sigma_{\gamma\gamma}}{dt} + \frac{W^2}{4\pi}\int e^{i\vec{q}\vec{\rho}}\, d^2\rho\, \Omega_{\gamma\gamma,\gamma\gamma}(\vec{\rho})\,\Omega_{\rho\rho,\rho\rho}(\vec{\rho}) \times \frac{A - N(0,\tilde{\sigma})}{\tilde{\sigma}} . \tag{2}$$

Expanding the second term in Eq.(2) in powers of $\frac{-\partial}{\sigma}$, one can obtain corrections to the leading term corresponding to rescatterings with the change of the direction of motion. For example, retaining only the first term of the expression, it is easy to find from Eq.(2)

$$\frac{d\sigma_L}{dt} = A\frac{d\sigma_{\gamma\gamma}}{dt} + W^2\frac{\sigma^{el}}{2\sigma}e^{aq^2/2}\left[A - N(0,\tilde{\sigma})\right]\frac{d\sigma_{\gamma\gamma}}{dt} , \tag{3}$$

where σ^{el} is the total cross section for elastic process $\rho N \to \rho N$ "a" is the slope in the amplitude of this process.

Thus, measuring the differential cross section for the process $\gamma A - \gamma A'$ at large momentum transfers and at energies $E_\gamma \lesssim$ 3 GeV, one finds the parameter W, the difference of which from unity characterizes the degree of violation of the vector dominance model. Note, that in the photoabsorbtion experiments on nuclei (Compton - effect in the forward direction) at such energies this possibility is absent $\left(\sigma(\gamma A) = A\sigma(\gamma N)\right)$

Consider now the high-energy case $(\Delta\ell << 1)$ Using the same approximation as in the low-energy limit, we can obtain for differential cross section of γ -nucleus scattering

$$\frac{d\sigma_H}{dt} = A\,(1-W)^2\frac{d\sigma_{\gamma\gamma}}{dt} + 2W(1-W)N_1\left(\frac{\sigma}{2}\right)\frac{d\sigma_{\gamma\gamma}}{dt} + \frac{h^4W^2}{4\pi}\int e^{i\vec{q}\vec{\rho}}\, d^2\vec{\rho}\ \times$$

$$\times\left(e^{-\tilde{\sigma}T(b)}-e^{-\sigma T(b)}\right)d^2B,$$

$$N_1\left(\frac{\sigma}{2}\right)=\int d^2b\, T(b)\, e^{-\frac{\sigma}{2}T(b)};\quad T(b)=\int_{-\infty}^{\infty}\rho(b,z)\,dz;$$

$$h^2=\frac{f_{\gamma\gamma}(0)}{f_{\rho\rho}(0)}$$

If the vector dominance model is valid (W=1), Eq.(4) takes the form

$$h^{-4}\frac{d\sigma_H}{dt}=\frac{1}{4\pi}\int e^{i\vec{q}\vec{\beta}}d^2\beta\left(e^{-\tilde{\sigma}T(b)}-e^{-\sigma T(b)}\right)d^2B.$$

The expression on the right-hand side of this equality is the cross section for quasi-elastic scattering of hadrons on nuclei [7].

The obtained result allows a simple physical interpretation [2]. If the energy increases, the photon lifetime δ in a hadron state (in our case in ρ - or ω -state) also increases.

Indeed, according to the uncertainty relation, $\delta\approx\frac{1}{\Delta E}=\frac{1}{|E_\gamma-E_\rho|}\approx\frac{2P}{m_\rho^2}$ and, therefore, at energies considered $(\ell<<\delta)$ photons behave as hadrons.

Since the cross section for quasi-elastic scattering of hadrons on nuclei varies with the increasing of atomic number approximately as $A^{2/3}$, the deviation from this dependence in the high energy region $(\ell<<\delta)$ is determined by the difference of the parameter W from unity*), as it follows from Eq.(4).

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*) In the same assumption that were used to deduce Eq.(4), for the total cross section of photoabsorbtion on a nucleus we get (for simplicity we assume the amplitudes to be purely imaginary):

$$\sigma(\gamma A)=\sigma(\gamma N)\left\{A-W\left(A-N\left(0,\frac{\sigma}{2}\right)\right)\right\}$$

Using the fact that [3] $\sigma(\gamma A)\sim A^{0,9}$ and putting $\sigma=\sigma(\rho^0 N)=26\,mb$, we can obtain $W\approx 0.6$.

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It is worth-while to note that if one measures the differential cross section for the discussed process at the momentum transfers $|t| \gtrsim 0,8-1\left(\frac{Gev}{c}\right)^2$, the A-dependence of this quantity must be described by the law $A^{2/3}$ irrespective of the value of W.

This result is due to the third term of Eq.(4) which involves effects from multiple rescatterings with a change of the direction of propagation, that become dominating at the momentum transfers $|t| \gtrsim 0,8-1\left(\frac{Gev}{c}\right)^2$.

The experimental study of the incoherent photon-nucleus scattering, thus, will make it possible to obtain detailed information on the mechanism of interaction of particles with nuclei.

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