$[\theta^0] = ([n] + \Lambda^0)$ and $[\theta^+] = ([p] + \Lambda^0)$ correspond to the doublet $\theta^0 = (n + [\Lambda^0])$ and $\theta^+ = (p + [\Lambda^0])$ [2].

2. At present, in addition to the Λ^0 hyperon, there exist the hyperon $\Sigma^{\pm}$ and, to all appearances, Σ^0 [4,7] with a mass $\sim 2370\, m_e$, all of which decay into a nucleon and a π-meson. It is natural to consider them as forming an isotopic triplet*. Assuming that these hyperons are excited nucleons, it is natural, in the light of the Fermi-Yang hypothesis, to permit the existence of heavy mesons, each consisting of a system of a nucleon and a $[\Sigma]$. We shall label these hypothetical particles as θ_1. The isotopic spin of the θ_1 particle can be 1/2 or 3/2.

If the difference in mass between the θ_1-and θ-particle exceeds the π-meson mass, then the interaction in which the isotopic spin is directly conserved and which is strong, according to the Gell-Mann scheme[2], leads to the decay $\theta_1 \rightarrow \theta + \pi$ with an extremely small lifetime ($\sim 10^{-22}$ sec). (We assume that no "unexpected" exclusion rules exist here.)

If the difference in mass between θ_1 and θ is smaller than the π-meson mass, then an electromagnetic interaction which conserves the Z component of the isotopic spin induces, practically instantaneously, a decay of the form $\theta_1 \rightarrow \theta + \gamma$ (analogous to the decay $\Sigma^0 \rightarrow \Lambda^0 + \gamma$ [4,7]). Only the θ^{++}-particle may be "stable" (in the case that the isotopic spin of θ_1 equals 3/2 and the emission of a π-meson is forbidden by the energetics).

Note added in proof: After the communication of this letter, the author learned that M.A. Markov[8] considered particles analogous to the θ_1-particle.

* We are not considering the "cascade" hyperon Ξ^- ($\Xi^- \rightarrow \Lambda^0 + \pi^-$) since at present there are no experimental data which permit one to make definite conclusions concerning the isotopic spin of Ξ.

[1] E. Fermi and C. Yang, Phys. Rev. **76**, 1739 (1949).

[2] M. Gell-Mann, Phys. Rev. **92**, 833 (1953).

[3] M. A. Markov, Dokl. Akad. Nauk SSSR **101**, 451 (1955).

[4] W. B. Fowler, R. P. Shutt, et al., Phys. Rev. **98**, 121 (1955).

[5] J. Ballam, A. L. Hodson et al., Phys. Rev. **97**, 245 (1955).

[6] I. C. Shapiro, J. Exptl. Theoret. Phys. (U.S.S.R.) 27, 257 (1954).

[7] W. Walker, Phys. Rev. **98**, 1407 (1955).

[8] M. A. Markov, *The Systematics of Elementary Particles*, Academy of Sciences Press, Moscow, 1955.

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Production of a Nuclear Star and π-Meson by a Gamma Photon

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POMERANCHUK has considered[1] the production of a π-meson pair by a collision between a γ-photon and a nucleus where, in the final state, there was a π-meson pair while the nucleus suffered only a slight recoil. In the present work a process is considered in which one of the mesons of the resulting π-meson pair is absorbed within the struck nucleus and produces a nuclear "star". Thus, one has an unusual mechanism for the creation of nuclear "stars" by γ-photons where, in the final state, one also has a fast π-meson which carries off energy of the order of the total energy of the star. All considerations are ultra-relativistic and only the small angles between the γ-photon momentum and the emitted π-meson momentum play an essential role. For these conditions on the indicated process, distances greater than the dimensions of the nucleus play the same role as in the formation of a free π-meson pair[1,2]. This follows from a consideration of the corresponding integrals and is tied in with the small longitudinal transfer of momentum to the nucleus in the process of pair formation (from the uncertainty relation $\Delta r_{||} \simeq h/\Delta p_{||}$).

The intense interaction of the π-mesons with nuclei implies that the nucleus can be considered, in the first approximation, as "absolutely black" as regards π-mesons.

In this process the absorbed meson exists in the same condition as in the process of γ-photon emission where a meson is absorbed by a nucleus. This process was studied by Landau and Pomeranchuk[3] by a suitably constructed Green's function and by an approximate solution of the corresponding wave equation. An analysis of their resulting expressions indicated, however, that the process can be studied with the aid of a radiation transition matrix element in which the absorbed meson is represented as a spherical wave converging on an arbitrary point of the nucleus and the square of the modulus of the matrix element must be integrated across the nucleus cross section. Consequently, we shall represent the meson absorbed in our process by a converging spherical wave.

The matrix element has the form

$$M=\frac{e}{i}\sqrt{\frac{2\pi}{\omega}}\int[\psi_1^*(j\nabla)\psi_2^*-\psi_2^*(j\nabla)\psi_1^*]\,e^{i\vec{\omega}\mathbf{r}}d\mathbf{r} \quad (1)$$

($\hbar=c=1$) where ω is the γ-photon frequency and j is its polarization. Let us apply index 2 to the free meson which we describe by a plane wave plus a converging wave diffracted by the "absolutely black" nucleus[1]

$$\psi_2=\frac{1}{\sqrt{2E_2}}\left[e^{i\mathbf{p}_2\mathbf{r}}+\frac{p_2}{2\pi i}\int\frac{e^{-ip_2|\mathbf{r}-\mathbf{s}_2|}}{|\mathbf{r}-\mathbf{s}_2|}d\mathbf{s}_2\right], \quad (2)$$

where E_2 and $\mathbf{p}_2$ represent the energy and momentum of the escaping meson, $E\gg\mu$. The integration over $\mathbf{s}^2$ is carried over a circle of radius R perpendicular to $\mathbf{p}_2$ and passing through the nucleus center; πR^2 is the cross section for all inelastic collisions between the π-meson and the nucleus. Furthermore,

$$\psi_1=\frac{\sqrt{p_1}}{4\pi^{3/2}}\frac{e^{-ip_1|\mathbf{r}-\mathbf{s}|}}{|\mathbf{r}-\mathbf{s}|}=\frac{\sqrt{p_1}}{8\pi^{7/2}}\int\limits_{\varepsilon\to 0}\frac{e^{-i(\mathbf{q},\,\mathbf{r}-\mathbf{s})}}{q^2-p_1^2+i\varepsilon}d\mathbf{q}, \quad (3)$$

where the normalization is so chosen that the differential cross section for the process has the form

$$d\sigma_j(p_2,\mathbf{k}_2)=2\pi\int|M|^2ds\,|F|^2(2\pi)^{-3}dp_2d\mathbf{k}_2. \quad (4)$$

Here $\mathbf{k}_2$ is the transverse momentum of the escaping π-meson, $\omega\cdot\mathbf{k}_2=0$ and F is a constant (form-factor) which allows for the possibility of a nonlocal interaction of the π-particles with the nuclear background[1-3]. Comparison of the theoretical conclusions with experimental facts will permit one to specify this constant, which is of great interest to the theory.

Thus, the outlined method is based on a very strong interaction between the mesons and the nucleons while the interaction with the electromagnetic field is considered in the first approximation of perturbation theory. It has proved possible to carry out the calculation for heavy nuclei, i.e., $\mu R\gg 1$, where μ is the rest mass of the meson. For the differential cross section we have,

$$d\sigma_j(p_2,\mathbf{k}_2)=\frac{e^2}{2\pi^2}\frac{E_2(\omega-E_2)}{\omega^3}R\frac{1}{\mu\eta^2\sqrt{1+\eta^2}}\left\{E(\varepsilon)\left(\frac{\cos^2\varphi}{1+\eta^2}-\sin^2\varphi\right)+K(\varepsilon)\left(\frac{\eta^2-1}{\eta^2+1}\cos^2\varphi+\sin^2\varphi\right)\right\}|F|^2dE_2d\vec{\eta}, \quad (5)$$

where $\vec{\eta}=k_2/\mu$; $\epsilon^2=\eta^2/(1+\eta^2)$; $\mathbf{j}\mathbf{k}_2=k_2\cos\varphi$; $d\vec{\eta}=\eta d\eta d\varphi_\eta$; K and E are the complete elliptical integrals of the first and second kind, respectively.

Averaging of the polarization of the γ-photon we obtain

$$d\sigma(E_2,\mathbf{k}_2)=\frac{e^2}{4\pi^2}\frac{E_2(\omega-E_2)}{\omega^3}R\frac{1}{\mu(1+\eta^2)^{3/2}}\times(2K(\varepsilon)-E(\varepsilon))|F|^2d\vec{\eta}dE_2. \quad (6)$$

From Eq. (6) it is evident that the effective $\eta\sim 1$, i.e., the effective angles $\theta\sim\mu/E_2$. The form-factor F can be determined by comparing Eq. (6) with experimental data.

We note that, even though the total cross section appears small compared to the nucleus, the differential cross section for small angles has larger values for greater E_2. Thus for $\eta=1$, the differential cross section equals

$$d\sigma/d\vartheta dE_2=e^2E_2(\omega-E_2)\,\omega^{-3}(E_2^2/\mu^2)(R/\mu). \quad (7)$$

For larger values of E_2 the factor E_2^2/μ^2 can compensate for the small factor e^2.

One can integrate, if one sets $F=1$, Eq. (6) over E_2 and η. Performing the integration with η varying from 0 to some $\eta_{max}\sim 1$, we obtain

$$\sigma=(e^2/12\pi)(R/\mu)\,\Phi(\eta_{max}); \quad (8)$$

$$\times\Phi(\eta_{max})=\int\limits_0^{\eta_{max}}\left[2K\left(\frac{\eta}{\sqrt{1+\eta^2}}\right)-E\left(\frac{\eta}{\sqrt{1+\eta^2}}\right)\right]\frac{\eta d\eta}{(1+\eta^2)^{3/2}}. \quad (9)$$

The value of η_{max} is defined by the fact that we have neglected the form-factor and also by the fact that all considerations are applicable for small angles.

The total cross section does not depend upon the photon energy and is proportional to R/μ rather than R^2, i.e., the periphery of the nucleus with a width of $1/\mu$ enters into the cross section. This circumstance is due to the wave properties of the π-mesons. Actually, in the region effective for the process (in front of the nucleus) the ψ-function of the escaping meson has a shadow and the entire process is determined within the region of the penumbra.

If we set $\eta_{max} = \infty$, then

$$\sigma = (\pi/32)\, e^2 R/\mu \sim 10^{-28}\ \text{см}^2. \qquad (10)$$

The preceding considerations were based on a specific model of the nucleus, viz., an "absolutely black" sphere of radius R. Employing a method developed in Ref. 2, one can generalize the problem to any arbitrary law of interaction between π-mesons and nucleons. The correction for semi-transparency which occurs for the case of strong absorption by heavy nuclei is of the order of $1/\mu R$ to the cross section for "black" nuclei.

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[1] I. Ia. Pomeranchuk, Dokl. Akad. Nauk SSSR **96**, 265, 481 (1954).

[2] Iu. A. Vdovin, Dokl. Akad. Nauk SSSR **105**, 947 (1955).

[3] L. D. Landau and I. Ia. Pomeranchuk, J. Exptl. Theoret. Phys. (U.S.S.R.) **24**, 505 (1953).

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Contribution to the Theory of Reactions Involving Polarized Particles

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THE general theory of the correlation phenomena which depend on the law of conservation of the total angular momentum has been considerably developed in Refs. 1-3.

We have obtained the tensor momenta (see the determination below) for the two body problem in the most general case, when the incident and scattered particles and the particles of the target are in arbitrary spin states (for example, polarized).

The diagonality of the S-matrix with respect to the total impulse, total energy E, total angular momentum J and its projection M is made use of, and the transformation theory of Dirac[4] is applied systematically. The advantage of such an approach lies in the fact that it establishes a direct connection between its results and the conservation laws, allows errors and inexactitudes to be avoided more easily than in other approaches[2-5] and allows a direct generalization to the case of reactions involving more than two particles.

The reaction $a + b \to \Lambda + \theta$ was considered. Particles Λ and θ are in general different from a and b. All the particles have spins and rest masses not equal to zero (they could be either nuclei or "elementary" particles).

All the investigations are caried out in the center of mass system; hence, the indices of the total impulse and the diagonality with respect to them are not shown expressly.

The elements of the S-matrix have the form:

$$(i_\Lambda i_\theta s' l' \alpha' \,|\, S^{JE} \,|\, i_a i_b s l \alpha)\, \delta_{JJ'} \delta_{MM'} \delta(E' - E) \qquad (1)$$

where the symbols are as follows: i_Λ, i_θ are the particle spins, s and s' are the total orbital angular momenta of the two particles relative to the center of mass before and after the reaction, respectively, α and α' are the remaining variables which are not specified here (for example, variables connected with the internal state of the particles). Equation (1) is an expression of the conservation laws.

Since the magnitudes expressly shown above are not directly measured, but instead the directions of motion and the projections of the spins are measured, we must obtain the elements of an S-matrix corresponding to experiment from the elements of (1). In order to do this we must first of all go from the $s'l'J'M$ representation to the $s'\nu'l'\mu'$ representation (the corresponding unitary transformation is the matrix of the Clebsch-Gordan coefficients $C^{JM}_{s'\nu' l'\mu'}$), and then with the help of the transformation

$$i^l Y^*_{l'\mu'}(\vartheta_\Lambda \varphi_\Lambda)\, C^{s'\nu'}_{i_\Lambda \lambda i_\theta n}$$ [1]

go from the $l'\mu's'\nu'$ representation to the $\vartheta_\Lambda \varphi_\Lambda \lambda' n$ representation ($\vartheta_\Lambda \varphi_\Lambda$ are the spherical angles of