On the probability of excitation of high-spin states in the capture of π^--mesons by nuclei

S. S. Gershteĭn

Institute for High Energy Physics, Serpukhov (Moscow region)
Usp. Fiz. Nauk **124**, 455–457 (March 1978)

PACS numbers: 21.60.Gx, 25.80.+f

As a result of experimental investigations carried out during the last two years a new interesting phenomenon has been discovered—the excitation of high-spin nuclear states formed in the capture of negative pions (cf., the review article by S. M. Polikanov and D. Chultêm[1]). A detailed numerical calculation of this phenomenon involving a nuclear cascade was carried out in Ref. 2 using the Monte Carlo method. The object of the present note is to point out that the prinicpal special feature of the discovered phenomenon—the high probability for the formation of high-spin fragments,—can be qualitatively understood on the basis of very simple and easily visualizable considerations.

Indeed, in accordance with theoretical concepts and direct experimental indications, the capture from mesic atom orbits of negative pions by nuclei occurs by means of their being absorbed by nucleon clusters situated near the surface of the nucleus. We first consider the absorption of a pion by a two-nucleon ("quasideuteron") cluster at rest and assume that the emergence of the nucleons after the absorption of the pion occurs isotropically. Then (cf., Fig. 1) the probability of one of the nucleons emerging at an angle θ to the normal to the nuclear surface is proportional to $dW\sim\sin\theta d\theta$, while the angular momentum transferred to the nucleus in the case when the second of the two nucleons "gets stuck" in the nucleus, is equal to $M=p_0R\sin\theta$ (where R is the nuclear radius, $p_0\approx(m_\pi M_N)^{1/2}$ is the momentum with which the nucleons of the "quasideuteron" cluster separate after the capture of the pion, m_π, M_N are the pion and nucleon masses). Determining $\sin\theta=M/M_0$ ($M_0=p_0R$), and assuming for the purpose of making an estimate $R\approx(1/m_\pi)A^{1/3}$, we obtain for the probability of formation of nuclear fragments with angular momenta lying in the range M to $M+dM$ the expression

$$dW_M=\frac{M\,dM}{M_0^2\sqrt{1-(M^2/M_0^2)}},\quad M<M_0\approx A^{1/3}\sqrt{\frac{M_N}{m_\pi}} \tag{1}$$

For heavy nuclei ($A\approx200$) the maximum value of the angular momentum of an excited nucleus is $M_0\approx15$, and this with an accuracy of 2–3 units coincides with the maximum angular momentum observed experimentally. For a more accurate treatment it is naturally necessary to take into account the dynamics of the absorption of the nucleon in the nucleus, the smearing out of the nuclear boundary, the movement of clusters and the possibility of the pion being captured by more complicated clusters (for example, α-particles). One must also take into account the spin of the initial target nucleus and the angular momentum ($l=3$) introduced into the nucleus by the pion (since the capture of the pion according to experimental data occurs primarily from the $4f$ state). Such an investigation taking into account the set of factors enumerated above was carried out numerically on the basis of the nuclear cascade model.[2] The fact is important, however, that the increase in the probability of formation of nuclear fragments with large angular momenta predicted by formula (1), does not depend on the dynamics of the nuclear processes but follows from the purely "geometrical" factor ($\sin\theta d\theta$) which increases the statistical weight for high angular momenta in the case that the elements of the cluster separate isotropically. In this sense the excitation of high-spin nuclear states accompanying pion capture is analogous to the excitation of high-spin states observed by G. N. Flerov *et al.*[3] in reactions involving heavy ions (where the probability is given by $dW_M\sim MdM$)[1]. Since in the numerical calculations of nuclear cascades[2] which follow the process of the capture of a pion by a cluster an isotropic separation of nucleons of the two-particle cluster was assumed, the increase in the statistical weight for large angular momenta (1) was taken into account automatically and gave good agreement with the observed data. At the same time, it is clear that the high statistical weight for the production of high-spin states can manifest itself also in the case of other mechanisms of interaction in nuclear matter of nucleons emerging from a cluster. In particular, those cases are of interest in which the energy of the nucleon "stuck" in the nucleus is transferred in a coherent fashion to an association of nucleons within the nucleus. In such cases the formation of nuclear "quasimolecules" with high angular momenta (as is observed in reactions involving heavy ions)[2] is possible. In order to observe such phenomena it is necessary to study processes which follow the act of pion capture "instantaneously". The study of "instantaneous" processes is also of interest for the reconstruction of the "true" distribution with respect to angular momenta of the nuclear fragments since the method of separating out the long-lived isomers (an

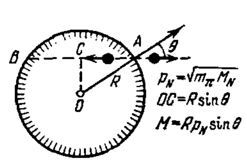

FIG. 1.

[1]The analogy mentioned above has been observed experimentally. As S. M. Polikanov *et al.* have noted the isomeric ratio for nuclear fragments in the case of pion capture is the same as in reactions with heavy ions.[3]

[2]It would also be of interest to check whether quasistable transuranic shape isomers could be formed in the case of pion capture due to "coherent" effects.

0038-5670/78/030223-02$01.10

exceptionally ingenious method in its simplicity which made possible the discovery of the phenomenon itself of the excitation of high-spin states) can, generally speaking, yield a somewhat distorted distribution due to prior rapid nuclear transitions. Expression (1) becomes inapplicable for $M \approx M_0$ since in the proposed model the values $M = M_0$ correspond to the emergence of the nucleons of the cluster parallel to the nuclear surface and, consequently, are incompatible with the assumption that the nucleon "gets stuck" in the nucleus. It is easy to obtain a qualitative estimate of the magnitude of the angular momentum M_1 up to which expression (1) will be valid by starting from the condition that in order for the nucleon to "get stuck" its trajectory in the nucleus (the segment AB in Fig. 1) must amount to several nuclear mean free paths. Assuming for the sake of definiteness a trajectory in the nucleus greater than 4–5 mean free paths, we obtain for heavy nuclei $M_1 \approx (0.7-0.6)M_0$. Thus, up to values of angular momenta of 9–10 the probability of excitation of high-spin states must increase with increasing angular momentum.

Qualitative confirmation of the simple model under consideration is provided by data on the multiplicity of the evaporated neutrons accompanying the process of pion capture by heavy nuclei. According to experimental data the evaporation of 6–8 neutrons turns out to be the most probable and this corresponds to an excitation energy of the residual nucleus of approximately 70 MeV (i.e., to the energy introduced by the nucleon that "gets stuck" in the case of a capture of a pion by a two-particle cluster at rest)[3]. It also should be noted that evaporated neutrons of energy of 2–5 MeV can with considerable probability take away from heavy nuclei angular momenta equal to $(1-2)\hbar$. It is necessary to take this circumstance into account in a more detailed investigation of this problem.

[3]With respect to theoretical interpretation of data on the neutron yield in the case of pion capture cf., Ref. 2, 4.

[1]S. M. Polikanov and D. Chultêm, Usp. Fiz. Nauk 124, 441 (1978) [Sov. Phys. Usp. **21**, 215 (1978)].
[2]A. S. Il'inov, V. I. Nazaruk and S. E. Chigrinov, Nucl. Phys. A **268**, 513 (1976).
[3]G. N. Flerov *et al.*, Yad. Fiz. **6**, 17 (1967) [Sov. J. Nucl. Phys. **6**, 12 (1968)].
[4]M. P. Locher and F. Myhrer, Helv. Phys. Acta **49**, 123 (1976).

Translated by G. Volkoff