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V.S.Butsev, D.Chultem

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Бутцев В.С., Чултэм Д. **E15 - 10226**

Вероятность однонуклонного поглощения пионов и проблема пи-конденсата

Определена вероятность однонуклонного поглощения пиона в ядре. Она оказалась меньше чем 10^{-5}.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Butsev V.S., Chultem D. **E15 - 10226**

Pion Single Nucleon Absorption and the Problem of Pion Condensation

The probability of pion nonradiative absorption by a single nucleon in nuclei experimentally has been found to be smaller than 10^{-5}.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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Due to energy and momentum conservation laws the single nucleon absorption of pions involves the nucleon momentum of 500 MeV/c. This value exceeds essentially the nucleon momentum cut-off inside the nucleus. Thus, the single nucleon mode of pion absorption is generally quoted as strongly suppressed.

In 1951 Brueckner, Serber and Watson[1] developed the two-nucleon (quasideuteron) model of pion absorption which was subsequently confirmed by a variety of experiments, in particular, by the observation of the back-to-back emission of two fast nucleons[2].

However, the theory of the finite Fermi-system implies possible appearence of spin-isospin density waves (pion condensation)[3]. The rescattering of nucleons by these density fluctuations is likely to cause the pion single nucleon absorption to be substantially enhanced[4].

Since the correlated emission of nucleons has been observed only for light nuclei and the pion condensation is best preferred in heavy nuclei, the experimental determination of single nucleon absorption probability was of importance.

The capture of stopped pions by ^{181}Ta nuclei was studied experimentally in this work.

It is known[5,6] that pion absorption from the atomic orbits happens within the nuclear surface. Therefore, if single nucleon absorption takes place, among the products of the reaction $^{181}Ta(\pi^-, xN)$ the high-spin isomer $^{180m}Hf(8^-)$ has to be found as a result of rotating the nucleus by an emitted neutron. 130 MeV neutrons escaping from the nuclear surface can cause the angular momentum of about 15 $\hbar$.

By choosing the high-spin spectator we have reduced the background from the pion radiative absorption with the subsequent evaporation of one neutron.

Panofsky et al.[7] have shown that pion absorption by a free proton has two different channels:

$$\pi^- + p \begin{cases} n + \pi^0 & (60\%) \\ n + \gamma & (40\%) \end{cases}$$

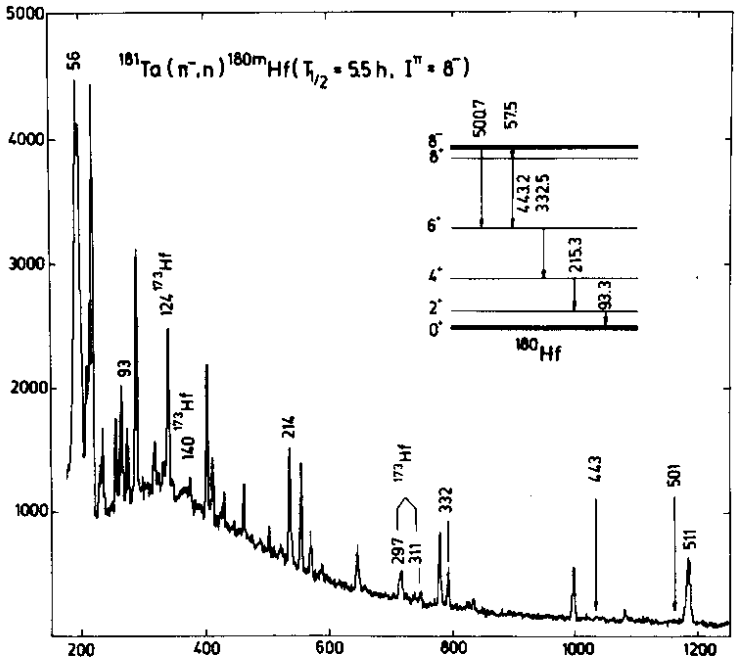
However, for pion absorption by a complex nucleus the charge exchange channel has a probability of about 10^{-5} [8] and the radiative capture channel has a probability of about 10^{-2} [9].

Consequently, charge exchange on a bound proton in ^{181}Ta with the emission of one neutron gives a contribution to ^{180m}Hf production not larger than 10^{-5}. As to radiative capture, a 100 MeV gamma-quantum cannot cause the angular momentum $I = E_\gamma / c \times R$ larger than $3\hbar$, where R is the nuclear radius.

It is easy to show that the total angular momentum resulting from the initial nucleus spin $7/2\hbar$, the pion orbital momentum

3h, the high energy gamma recoil, etc., should give rise to a small contribution to the high-spin isomer ^{180m}Hf.

The figure shows a gamma-ray spectrum of a pion irradiated Ta target measured for 3 hours after a 1.5 hour exposure and 5.5 hour cooling.



Gamma-ray spectrum of a stopped pion irradiated Ta target.

The decay scheme of ^{180m}Hf has been well studied and its six intensive lines: 57.6 (48), 93.3 (17), 215.3 (80), 332.3 (93), 443.2 (84), 500.7 (13) keV are known. (Numbers in brackets are transitions per 100 decays, i.e., quantum yields)[10].

But the first four gamma-rays of these expected ones interfere with those from the decay of ^{178m}Lu produced in the Ta(π^-,p2n) reaction. Therefore, the ^{180m}Hf isomer can be identified only by two lines, i.e., 443.2 and 500.7 keV.

To determine the probability of single nucleon absorption the relative yields of the ^{180m}Hf isomer and ^{173}Hf isotope ($T_{1/2}$ = = 24 h) intensively produced in the reaction Ta(π^-,8n) were compared.

The yields have been calculated according to the following formula:

$$Y = \frac{S\lambda}{(1-e^{-\lambda t_1})e^{-\lambda t_2}(1-e^{-\lambda t_3})\cdot \epsilon \cdot k},$$

where S- is a photopeak area, ϵ is a detection efficiency, f is a quantum yield, K is a self-absorption coefficient, λ is a decay constant, t_1, t_2, t_3 are irradiation, cooling and measuring times.

No 443 and 501 keV lines have been found in the gamma-ray spectrum above the background level.

The yield of the ^{173}Hf isotope was determined by 124, 140, 297, 311 keV lines.

The upper limit for the yield ratio has been estimated to be:

$$Y(^{180m}Hf)/Y(^{173}Hf) \lesssim 10^{-4}.$$

If one takes into account that in the pion capture a dozen isotopes are produced, then the probability of pion absorption by a single nucleon can be estimated to be smaller than 10^{-5}.

In all the estimations the probability of secondary nucleon interaction with the nucleus has been assumed intuitively to be small.

The obtained experimental result shows that nonradiative pion capture in the nucleus occurs on nucleon associations but not on individual nucleons. This agrees with the theoretical conclusions of the quasi-deuteron model of Brueckner-Serber-Watson [1] as well as the alpha-particle model of Shapiro-Kolybasov [11].

This conclusion does not contradict the analysis of the high energy part of neutron spectra following π^- capture in different nuclei [12].

And at last, if there is unambiguous interconnection between the single nucleon absorption of the pion and π-condensation [4], indeed, the experimental result can be accepted as some indication that π-condensation in finite normal nuclei is rather controversial.

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