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THE PROBABILITY OF THE REACTION (π^-, p) AND THE EXISTENCE OF Δ- ISOBARS IN THE ATOMIC NUCLEUS

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Вероятность реакции (π^-, p) и проблема существования Δ -изобар в атомных ядрах

Изучен процесс однонуклонного поглощения медленных π^- -мезонов атомными ядрами ${}^{45}_{21}Sc$, ${}^{59}_{27}Co$, ${}^{89}_{39}Y$, ${}^{133}_{55}Cs$, ${}^{141}_{59}Pr$, ${}^{197}_{79}Au$ с последующей эмиссией одного протона. Вероятность однопротонной эмиссии определена с помощью активационной методики по выходу образующихся изотопов и составляет соответственно: ${}^{45}_{21}Sc(\pi^-,p)\,{}^{44}_{19}K$ – $W \le 6{,}1\cdot 10^{-4}$; ${}^{59}_{27}Co(\pi^-,p)\,{}^{58}_{25}Mn$ – $W \le 0{,}87\cdot 10^{-4}$; ${}^{89}_{39}Y(\pi^-,p)\,{}^{88}_{37}Rb$ – $W \le 6{,}9\cdot 10^{-4}$; ${}^{133}_{55}Cs(\pi^-,p)\,{}^{132}_{53}I$ – $W \le 1{,}3\cdot 10^{-4}$; ${}^{141}_{59}Pr(\pi^-,p)\,{}^{140}_{57}La$ – $W \le 3{,}0\cdot 10^{-4}$; ${}^{197}_{79}Au(\pi^-,p)\,{}^{196m}_{77}Ir$ – $W \le 3{,}3\cdot 10^{-5}$ на один остановившийся пион.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

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The Probability of the Reaction (π^-,p) and the Existence of Δ-Isobars in the Atomic Nucleus

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1. INTRODUCTION

It is known that two-nucleon emission is the main channel of slow π^- absorption and the probability of the single-nucleon mechanism of pion absorption is negligibly small.

Numerous attempts have been made to measure experimentally the probability of non-radiative single-nucleon absorption involving the emission of a single neutron, (π^-, n), and a single proton, (π^-, p) . However, none of these attempts has given unambiguous results.

In recent years the non-radiative absorption of negative pions has been of particular interest in connection with the widely discussed problem of the existence of a pion condensate /1/ and Δ -isobars /2/ in the atomic nucleus.

To verify theoretical predictions concerning the increasing role of the single-nucleon mechanism of pion absorption in the case of the existence of the pion condensate in common nuclei /3/ , the probability of the reaction ${}^{181}Ta(\pi^-,n){}^{181m}Hf$ was investigated /4/. In the present paper the upper limit of this reaction probability has been determined to be $W_{1n} \le 10^{-5}$ per stopped pion.

The probability of the single-nucleon mechanism of pion absorption can be estimated by thoroughly measuring the high-energy part of the neutron spectrum. At an energy $E_n \simeq 100$-120 MeV, the spectrum is expected to exhibit some structure associated with the single-neutron emission rate. In fact, in a recent study carried out by a CERN group with a number of light nuclei such as ${}^6Li$, ${}^7Li$, and ${}^{12}C$ distinct peaks corresponding to the single-neutron emission have bee observed in the high-energy part of the inclusive neutron spectrum. These peaks are due to the single-neutron emissio , which occurs with a probability of $(1-2)\times 10^{-3}$ per stopped pion. However, in the same study it has been shown that as the level density of the final nucleus increases, it becomes impossible to single out the peaks corresponding to single-neutron emission. Consequently, in the case of complex nuclei, where π-condensation is most likely to manifest itself the mentioned technique turns out to be unsuitable.

At present the so-called activation technique appears to be the most promising for determination of the probability of the single-nucleon mechanism of π^-- absorption in complex nuclei. However, this technique has some disadvantages. One of the main disadvantages of this technique when used to study the single-nucleon mechanism of pion absorption is the difficulty in the separation of the non-radiative (π^-,n) and radiative $(\pi^-,\gamma n)$ reaction channels. The radiative pion capture has a rather high probability, ~2-3%, and is characterised by a wide excitation spectrum of the residual nucleus; this also leads to a noticeable probability of slow neutron emission/6/. Therefore, the experimentally measured probability of the reaction (π^-,n) should be regarded as the sum of the two processes (π^-,n) and $(\pi^-,\gamma n)$ or as the upper limit of each of them.

The slow π^--absorption followed by single-proton emission has been studied only by using the activation technique/7,8/. In ref./7/ the probability of the reaction $^{12}C(\pi^-,p)^{11}Be$ was determined to be equal to $(4.5 \pm 0.8) \times 10^{-4}$. The probability of this reaction seems to be overestimated because of the satellite reaction $^{13}C(\pi^-,pn)^{11}Be$. In ref./8/, the probability of the reaction $^{133}Cs(\pi^-,p)^{132}I$ was derived from the yield of the isotope ^{132}I and was equal to $(5.0 \pm 0.5) \times 10^{-4}$. This value is also overrated since the yield of ^{132}I was determined according to the 773 keV γ-line, which could not be separated from the 775 keV γ-line due to ^{124}I in the experiment, and the total area of these two lines was used to determine the probability of this reaction. In addition, the single-proton emission probability measured in those experiments should also be regarded as the sum of the probabilities of the two processes (π^-,p) and $(\pi^-,\gamma p)$ or as the upper limit of the probabilities of these processes taken separately.

In the present paper the activation technique was used to carry out experimental investigations of the single-nucleon mechanism of slow pion absorption in the Sc, Co, Y, Cs, Pr, and Au nuclei. The main point of these experiments was to detect the residual product nucleus with (A-1) and (Z-2) with respect to the A and Z of the initial nucleus, which was produced as a result of π^--absorption followed by the emission of a fast proton.

2. EXPERIMENTAL TECHNIQUE

Experiments were carried out at a pion beam from the JINR synchrocyclotron. Protons with an energy of about 680 MeV and with intensity of 2×10^{12} sec^{-1} were focussed, by a quadrupole lens system, onto a copper target which served as

the source of slow negative pions. Then E_π = 30 MeV pions were focussed onto the investigated target by a wide-angle solenoidal lens. The targets having the form of discs 30 mm in diameter and 2 g/cm^2 in weight were placed into capsules manufactured from borated polyethylene and cadmium. Pions retarted in the cadmium and borated polyethylene lasers were stopped in the target, the density of pion stops being equal to about 5×10^4 g^{-1} sec^{-1}.

The irradiation, "cooling" (from the termination of irradiation to the beginning of measurement) and measuring times were varied as a function of the half-life of the product nuclei expected to occur. The γ-radiation studies were performed using spectrometers consisting of Ge(Li) detectors of different volumes and with a 2.5 keV resolution for E_γ = 1332.5 keV of ^{60}Co. The series of the γ-ray spectra of the isotopes under investigation were transferred to a BESM-6 computer for subsequent treatment using standard programmes. A more detailed description of the experimental technique is given in a review paper/9/.

To investigate the single-nucleon mechanism of pion absorption experimentally, we specifically used only monoisotopic targets with wide-range Z and A values, $21 \le Z \le 79$ and $45 \le A < 197$, in particular: $^{45}_{21}Sc$, $^{59}_{27}Co$, $^{89}_{39}Y$, $^{133}_{55}Cs$, $^{141}_{59}Pr$, and $^{197}_{79}Au$.

3. EXPERIMENTAL RESULTS

The γ-ray spectra of the isotopes formed in the reactions $(\pi^-; \gamma n, xn)$ are shown in figs. 1-5 and 7. As has been noted in the introduction, it is necessary to identify the γ-lines due to the isotope with (A-1) and (Z-2) with respect to the target nucleus, which has been formed as a result of negative pion absorption followed by the emission of one proton. Let us consider each reaction separately.

3.1. The Reaction $^{45}_{21}Sc(\pi^-,p)^{44}_{19}K$ ($T_{1/2}$ = 22.2 min, $I^\pi = 2^-$)

The decay scheme of the isotope ^{44}K has been studied well/11/. A fragment of the decay scheme of ^{44}K and part of the γ-ray spectrum of the isotopes formed in the pion bombardment of a Sc target are presented in fig.1.

The most intensive γ-lines due to the decay of ^{44}K are at 1156.95 keV (58.1%) and 2151.3 keV (22.9%). The percentage quantum yields of these γ-rays per decay are given in parentheses. In the γ-ray spectrum, the 1157.0 keV γ-line has been identified and, according to its half-life, was attribu-

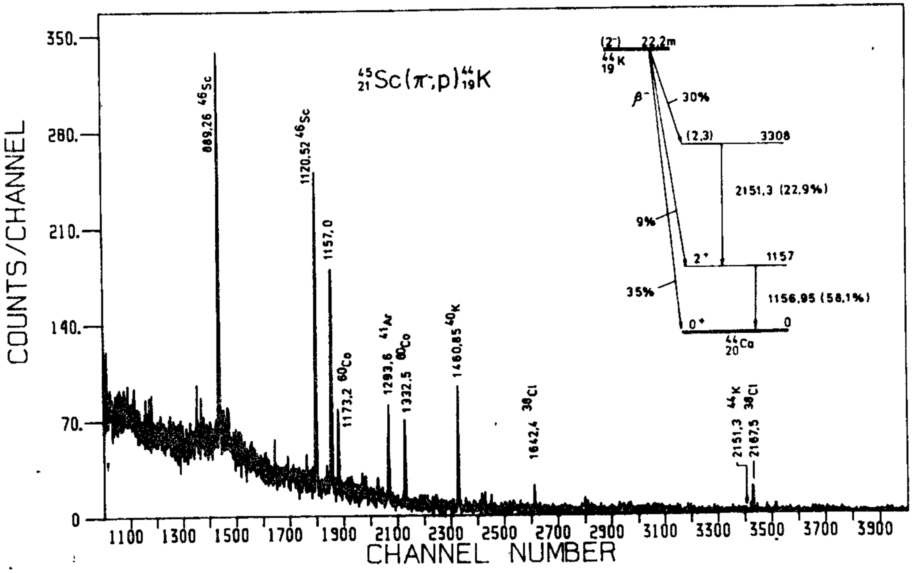

Fig.1. Fragment of the decay scheme of ^{44}K and part of the γ-ray spectrum of the isotopes produced in the reaction $(Sc+\pi^-)$.

ted to the isotope ^{44m}Sc (3.92 hrs) formed in the reaction ^{45}Sc(n, 2n). Therefore, the identification of the isotope ^{44}K can be done according to the 2151.3 keV γ-line, which could not be separated from the background under the optimal conditions of irradiation and measurement. In this case the upper limit of single-proton emission is equal to $\leq 6.1\times 10^{-4}$ per stopped pion.

3.2. The Reaction $^{59}_{27}Co(\pi^-, p)\,^{58}_{25}Mn$ $(T_{1/2} = 65$ sec, $I^{\pi} = 3^+)$

As the half-life of ^{58}Mn is only 65 sec, we carried out the cyclic activation of a ^{59}Co target and stored γ-spectra in a computer. A fragment of the decay scheme and part of the γ-ray spectrum obtained in the pion irradiation of the ^{59}Co target are shown in fig.2. The most intensive γ-transitions in the decay of ^{58}Mn correspond to 810.73 keV (61%), 863.9keV (10.4%) and 1323.1 keV (38.9%). The positions of the corresponding γ-lines expected are indicated with arrows. It should be noted that other magnesium isotopes are produced with appreciable probability by negative pion absorption in the ^{59}Co target. For instance, the isotope ^{56}Mn identified according

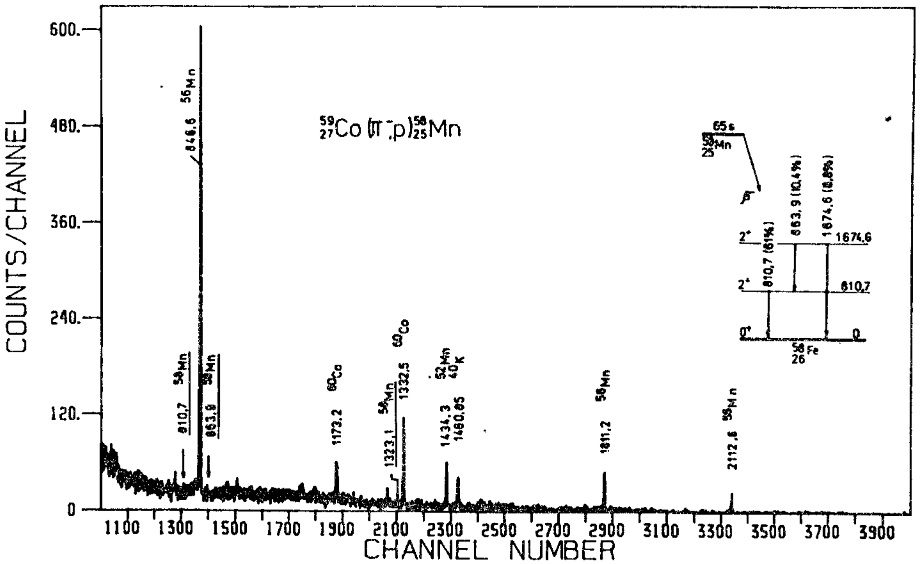

Fig.2. Fragment of the decay scheme of ^{58}Mn and part of the γ-ray spectrum of the isotopes produced in the reaction $(Co + \pi^-)$.

to the 846.6, 1811.2 and 2112.6 keV lines was produced in the reaction $^{59}Co(\pi^-, p2n)\,^{56}Mn$. This evidence indicates that the double-nucleon mechanism of negative pion absorption plays a predominant role. At this point it is important to note that by identifying the final product nucleus experimentally one can observe both the multi-nucleon and single-nucleon mechanisms of pion absorption simultaneously. Naturally, the contribution from the single-nucleon mechanism of pion absorption is small compared with the multi-nucleon one, and this is observed in the γ-ray spectrum.

The treatment of the γ-ray spectra using the specially developed programmes taking into account the efficiency curve for the Ge(Li) detectors, the coefficient of γ-ray self-absorption in the target and time factors, as well as the thorough approximation of background, have permitted determination of the probability of the reaction under investigation to be $W_{1p} \leq 0.87\times10^{-4}$ per stopped pion.

3.3 The Reaction $^{89}_{39}Y(\pi^-, p)\,^{88}_{37}Rb$ $(T_{1/2} = 17.8$ min, $I^{\pi} = 2^-)$

By bombarding a $^{89}_{39}$Y target with pions we obtained the γ-ray spectrum (fig.3) mainly due to the strontium and rubidium isotopes formed as a result of multi-nucleon emission. The ^{88}Rb decay occurs to the levels of the daughter nucleus ^{88}Sr (see the fragment of the decay scheme in fig.3). The isotope ^{88}Rb can be identified among the products of slow pion absorption according to the relatively intensive lines at 898.01 keV (12%) and 1836.13 keV (23%).

The positions of these γ-lines in the γ-ray spectrum are indicated with arrows. The appropriate handling of the γ-ray spectrum taking into account the time and geometric factors has only permitted estimation of the upper limit of the reaction $^{89}_{39}Y(\pi^-,p)^{88}Rb$ to be set at 6.9×10^{-4} per pion capture.

3.4. The Reaction $^{133}_{55}Cs(\pi^-,p)^{132}_{53}I$ ($T_{1/2}$ = 2.38 h, $I^{\pi} = 4^+$)

The preliminary results of determination of the probability for the reaction $^{133}Cs(\pi^-,p)$ are presented in ref.[8]. As noted in the introduction of the present paper, the probability of this process is somewhat overestimated because of the fact that the total area of the 772.1 keV and 775.1 keV γ-lines from ^{133}I and ^{124}I, respectively, was taken. We carried out additional experiments to determine the probability of this reaction more accurately.

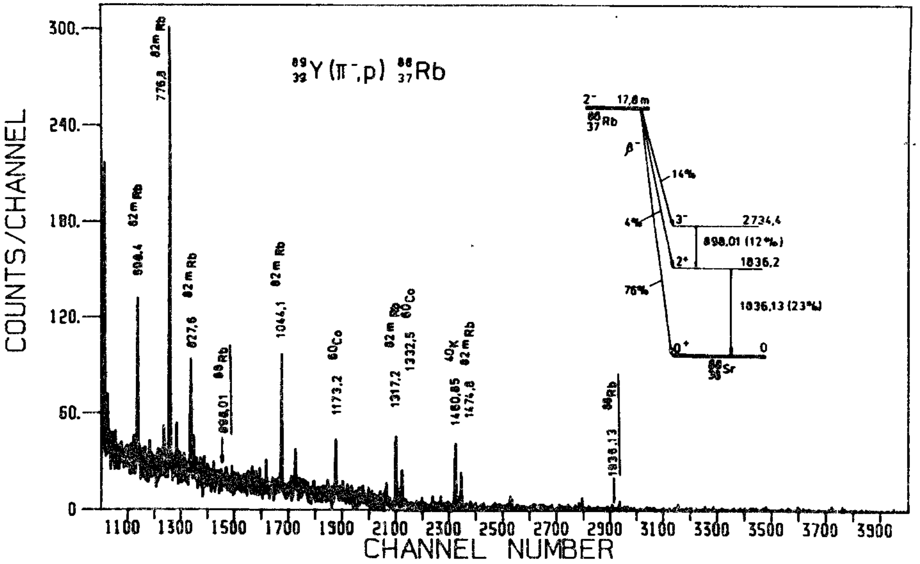

Fig.3. Fragment of the decay scheme of ^{88}Rb and part of the γ-ray spectrum of the isotopes produced in the reaction $^{89}Y(\pi^-,pxn)$.

During the process of π^- absorption in cesium nuclei a large number of xenon and iodine isotopes are produced in the reactions (π^-,xn) and (π^-,pxn), respectively. The isotopes of tellurium, antimony and tin are produced with smaller probability as a result of the emission of charged fragments and neutrons. The fact that a considerable part of the isotopes produced are radioactive and the γ-ray spectra obtained are complex makes it difficult for us to detect the rare reaction channel of interest. Therefore in the experiment we applied the high-efficiency technique of the radiochemical separation of the iodine fraction.

Part of the γ-ray spectrum due to the iodine fraction separated from pion-irradiated cesium chloride is shown in fig.4. This γ-ray spectrum contains the γ-lines only due to iodine isotopes with mass numbers from A=120 to A=132. The yield of the isotope ^{132}I can be determined according to the 772.7 keV (75%) and 667.8 keV (98%) γ-lines (see the fragment of the decay scheme in fig.4). However, the 667.8 keV γ-line due to ^{132}I coincides with the very intensive 668.4 keV γ-line from the isotope ^{130}I. We did not succeed in separating these γ-lines at 2.5 keV resolution for E_{γ} = 1332.5 keV of ^{60}Co. Therefore, the yield of ^{132}I was determined according to the 772.7 keV γ-line by expansion with the 775.1 keV γ-line from $^{124}_{53}I$ (see fig.4). Special

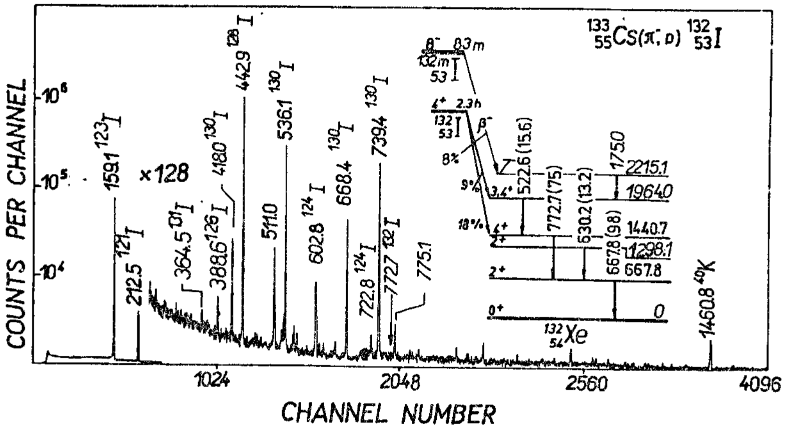

Fig.4. The γ-ray spectrum from the iodine isotopes produced in the reaction $^{133}Cs(\pi^-,pxn)$ and a fragment of the decay scheme for ^{132}I.

care was taken to control the background due to the reaction $^{133}Cs(n,2p)^{132}I$ on fast neutrons arising in the experimental hall during the operation of the accelerator. In the background experiment (fig.5) no 772.7 keV line has been observed in the γ -ray spectrum.

Thus, the thorough treatment of the γ -ray spectrum permitted determination of only the upper limit of the production probability for the isotope ^{132}I to be at a level of $\leq 1.3\times 10^{-4}$ per stopped pion.

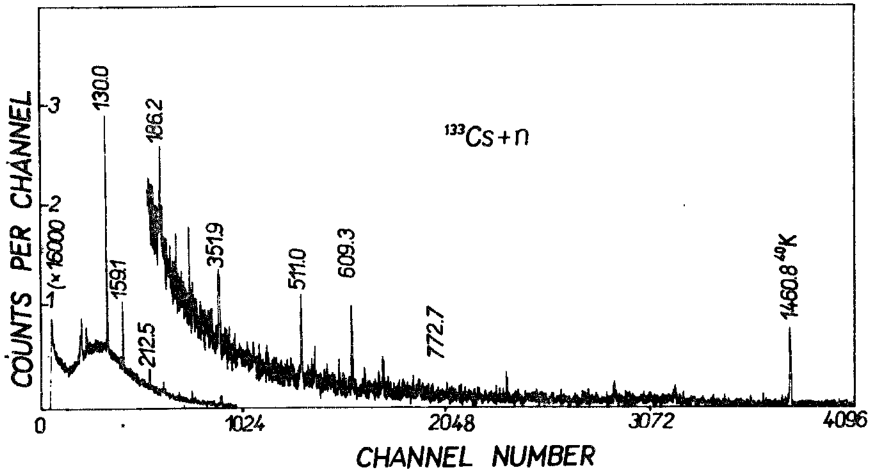

Fig.5. The γ-ray spectrum of the isotopes produced in the reaction ($^{133}Cs+n$).

3.5. The Reaction $^{141}_{59}Pr(\pi^{-},p)^{140}_{57}La$ ($T_{1/2}=40.2$ h, $I^{\pi}=3^{-}$)

The isotope ^{140}La has a comparatively long half-life, $T_{1/2}$ = 40.2 hrs, therefore, in order to reduce a contribution from short-lived activities, we carried out measurements for 6 hours after 54 hours following a 14-hour bombardment.

Fig.6 shows one of the γ-ray spectra of the long-lived products of the reaction ($^{141}Pr+\pi^{-}$). A fragment of the scheme of decay of ^{140}La to the levels of the daughter nucleus ^{140}Ce is also shown in this figure. The most intensive transitions in the decay scheme occur at 328.8 keV (20)%, 487.1 keV (46.7%), 815.7 keV (22.8%), and 1596.4 keV (96%). The positions of the corresponding γ-lines are indicated with arrows.

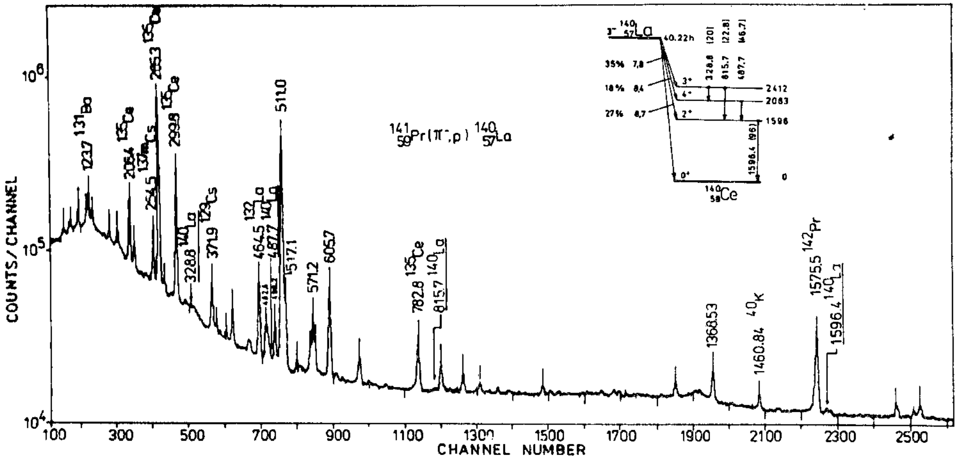

Fig.6. The γ-ray spectrum of the isotopes produced in the reaction $^{141}Pr(\pi^{-},pxn)$ and a fragment of the decay scheme of ^{140}La.

Special attention was paid to the purity of the ^{141}Pr target. If the ^{141}Pr target contains even small, about 0.5%, contaminations of other rare-earth elements, it is impossible to identify unambiguously the parent of the isotope ^{140}La. A ^{139}La admixture is particularly undesirable because it has a large resonance integral of thermal neutron absorption. An ~0.09% admixture of this isotope can lead to the production of ^{140}La in reactions induced by neutrons arising in the accelerator hall during the operation of the accelerator. Therefore the ^{141}Pr target was checked for the presence of the ^{139}La admixture by activation analysis technique at a resonance neutron beam from the JINR pulsed fast reactor IBR-30. Not any ^{139}La admixture has been detected in the ^{141}Pr sample up to a level of about 10^{-5}.

The treatment of the γ-ray spectra taking all the factors into account enabled us to determine the upper limit of single-proton emission for the reaction $^{141}Pr(\pi^{-},p)^{140}La$ to be at a level of $\simeq 3.0\times 10^{-4}$ per stopped pion.

3.6. The Reaction $^{197}_{79}Au(\pi^{-},p)^{196m}_{77}Ir$ ($T_{1/2}=1.4$ h, $I^{\pi}=10,11$)

As has been noted in the introduction, by measuring the reaction probability by activation analysis we determine the sum of the probabilities of all the processes leading to the emission of a single proton, or at least, the upper limit of each of these processes. The experimental investigation of the non-radiative single-nucleon absorption channel requires the choice of such a reaction, in which the fraction of other channels of negative pion absorption should be considerably smaller. Such a unique reaction is $^{197}\mathrm{Au}(\pi^-,p)^{196m}\mathrm{Ir}$, in which the isomer $^{196}\mathrm{Ir}$ can be produced only in the case of the non-radiative absorption of negative pions because other reaction channels do not contribute noticeably at the excitation of the high-spin isomer $^{196m}\mathrm{Ir}(10,11^-)$. In fact, in this case one of the main competing processes is the radiative capture of a negative pion (π^-,γ). The spin of the initial nucleus $^{197}\mathrm{Au}$ is equal to 3/2, and the pion orbital moment is equal to 3h ; therefore, the total angular momentum of the γ-ray with $E_\gamma =$ = 100-120 MeV, of the pion and the slow neutron is insufficient for the population of the state 11^- ($M = E_\gamma / c \cdot R$, where R is the nuclear radius).

The identification of the isotopes produced in the reaction $^{197}\mathrm{Au}(\pi^-;\gamma p, xn)$ has shown that the main reaction channel is the two-nucleon mechanism of negative pion absorption. Therefore, the platinum and iridium isotopes are produced with a large multiplicity of the emitted particles /10/ and with a noticeable probability. We should identify the isomer $^{196m}\mathrm{Ir}$ produced as a result of single-proton emission against the background of this principal process.

One of the γ-ray spectra of the isotopes produced by pion irradiation of a gold target and a fragment of the decay scheme of $^{196}\mathrm{Ir}$ are presented in fig.7. The γ-rays due to the isotopes $^{189}\mathrm{Pt}$ and $^{187}\mathrm{Pt}$ produced in the reactions $^{197}\mathrm{Au}(\pi^-,8n)$ and $^{197}\mathrm{Au}(\pi^-, 10n)$ respectively, the γ-rays from the isotopes $^{190}\mathrm{Ir}$ and $^{186}\mathrm{Ir}$ formed in the reactions $^{197}\mathrm{Au}(\pi^-,p6n)$ and $^{197}\mathrm{Au}(\pi, p10n)$ are identified in the spectrum. It is difficult to separate the rare channel of the single-nucleon mechanism of negative pion absorption from the background of the intensive γ-lines of the main process.

In the decay of the isomer $^{196}\mathrm{Ir}$, the $I^\pi = 11^-$ level of $^{196}\mathrm{Pt}$ (ref. /11/) is populated the rotational band of the isotope with high probability (see fig.7). Six intensive γ-lines from the decay of the isomer $^{196m}\mathrm{Ir}$ are known: 355.9 keV (94.3%), 393.5 keV (96.8%), 447.1 keV (94%), 521.4 keV (95.9%), and 647.3 keV (91.1%). The ground state of $^{196}\mathrm{Ir}$ has low spin $(0,1^-)$ and a short half-life, 52 sec. Therefore, the population of the rotational band levels occurs only as a result of the decay of the isomer $^{196m}\mathrm{Ir}$ (11^-).

The corresponding γ-lines due to the decay of $^{196m}\mathrm{Ir}$ are indicated with arrows in fig.7. The production probability for $^{196m}\mathrm{Ir}$, , or the probability of single-proton emission in the reaction $^{197}\mathrm{Au}(\pi^-,p)$, determined from the obtained experimental spectrum taking into account the geometric and time factors, is $W_{1p} \leq 3.3 \times 10^{-5}$.

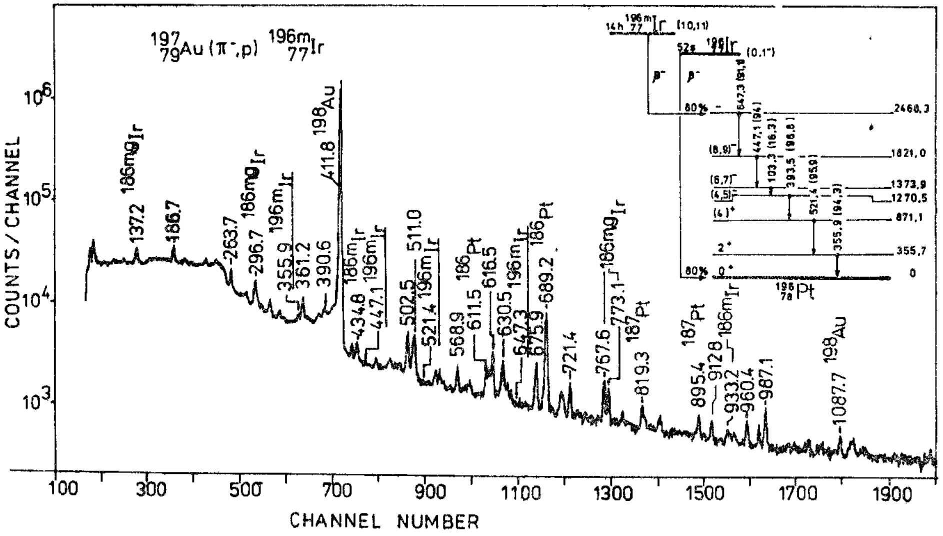

Fig.7. Fragment of the decay scheme of $^{196}\mathrm{Ir}$ and the γ-ray spectrum produced as a result of negative pion absorption in gold nuclei.

4. DISCUSSION OF RESULTS

The non-radiative absorption of slow pions followed by single proton emission can be regarded as the interaction of the pion with excited intranuclear nucleons, Δ-isobars, in the nuclear ground state, according to the following diagram:

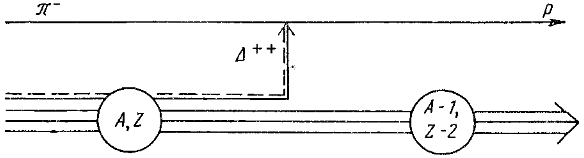

Fig.8. Diagram of the interaction of slow negative pions with a nucleus (A, Z), followed by fast proton emission.

The concept of virtual excited nucleons (Δ isobars) was introduced by A.Kerman and Kisslinger/12/to interpret the discrepancy between the experimental and theoretical values of cross sections for the interaction of forward scattered protons on deuterons.

Subsequently M.Goldhaber/13/reported on the observation of the scattering of energetic negative pions on deuterons in a bubble chamber. These events were indicative of the existence of Δ-components in the deuteron at a level of 0.7%.

In ref./14/, the Δ^{++} probability was investigated for the (p,π^-) reaction leading to the ground state in the final nucleus. This calculation took into account not only the Δ^{++}-contribution, but also contributions from multiple nucleon processes such as proton charge exchange (p,n) followed by a (n,π^-) reaction and intermediate π^0 production (p,π^0), and (π^0,π^-).

Experimentally/15/ the isotropic distribution of π^--mesons has been obtained in the reaction $^{26}Mg(p,\pi^-)^{27}Si$ for a proton energy of 185 MeV and for the Δ^{++}-transfer to the ground state in the final nucleus. The cross section was equal to about 0.6 nb/ster. This isotropic distribution is characterized by the predominance of multiple processes, as opposed to the sharp forward peaking obtained in calculations for reactions involving the Δ^{++} isobar. A comparison of the experimental and calculated cross sections of the (p,π^-) reaction enables one to set the upper limit of the $\Delta^{+\pm}$probability at a level of 10^{-3} - 10^{-4} for the Mg target nuclei.

The limits of the probability of single proton emission during stopped π^--absorption in Sc, Co, Y, Cs, Pr, and Au nuclei, obtained in the present paper (see the Table) yield the upper limit for the probability of the existence of the Δ^{++} on the nuclear surface at a lower level of 10^{-4}-10^{-5}, which can probably be accounted for by a smaller contribution from multiple processes occurring in the reaction investigated.

Now let us turn to the experimental results obtained in the present paper. The values of the probabilities of the non-radiative absorption of slow negative pions in the Sc, Co, Y, Cs, Pr, and Au nuclei are listed in the Table.

Thus, the probability of the reaction involving single proton emission ($\Delta A = -1$, $\Delta Z = -2$) for the nuclei investigated lies in the range from 10^{-5} to 10^{-4} per stopped pion. If the process of the non-radiative absorption of negative pions can be viewed upon as the interaction of pions with Δ isobars in the nucleus, as shown in the previous diagram in fig.8, from the experimental data obtained it follows that the probability of the existence of Δ isobars in complex nuclei is substantially lower than the probability obtained by M.Goldhaber for the deuteron.

Table

The probabilities of π^--absorption in the Sc, Co, Y, Cs, . Pr, and Au nuclei followed by single proton emission.

Nos.	I^π of initial nucleus	Reaction	I^π of final nucleus	Probability of reaction
1.	$7/2^-$	$^{45}_{21}Sc(\pi^-,p)\,^{44}_{19}K$	2^-	$\leq 6.1x10^{-4}$
2.	$7/2^-$	$^{59}_{27}Co(\pi^-,p)^{58}_{35}Mn$	3^+	$\leq 0.87x10^{-4}$
3.	$1/2^-$	$^{89}_{39}Y(\pi^-,p)^{88}_{37}Rb$	2^-	$\leq 6.9x10^{-4}$
4.	$7/2^+$	$^{133}_{55}Cs(\pi^-,p)\,^{132}_{53}I$	4^+	$\leq 1.3x10^{-4}$
5.	$5/2^+$	$^{141}_{59}Pr(\pi^-,p)^{140}_{57}La$	3^-	$\leq 3.0x10^{-4}$
6.	$3/2^+$	$^{197}_{79}Au(\pi^-,p)^{196m}_{77}Ir$	$(10,11^-)$	$\leq 3.3x10^{-5}$

These data can also be regarded as the upper limit of the radiative channel of slow pion absorption followed by proton evaporation $(\pi^-, \gamma p)$. It is known that the integrated probability of all channels of radiative capture (π,γ) amounts to 2-3%, while the experimentally determined probability of the reaction $(\pi^-,\gamma p)$ is equal to about 10^{-4}. Consequently it is possible to conclude that the probability of single proton evaporation from a nucleus with an energy of the order of 20 MeV lies at a level of about 10^{-2}. This result indicates the small yield of evaporated protons ($\leq 10^{-2}$) and can be qualitatively interpreted as being due to the effect of the Coulomb barrier on the nucleus. It should be noted that this process is very difficult to describe and the obtained, although indirect, experimental data may prove helpful for further theoretical studies.

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