СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E2 - 11296

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E2 - 11296

Распад состояний гигантского резонанса при радиационном захвате π^--мезонов в ядрах 1p-оболочки

Распад состояний гигантского резонанса, возбудившихся в процессе радиационного захвата π^--мезона ядрами мишени ^{9}Be, ^{11}B, ^{13}C и ^{14}N, рассматривается в рамках модели оболочек с промежуточной связью. Нижайшие возбужденные состояния дочернего ядра (A-1, Z-1) преимущественно заселяются от распада состояний промежуточного ядра, спин которых на две единицы больше спина ядра мишени. Предлагаются эксперименты на совпадение первичного γ-кванта со вторичным мягким γ-квантом.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1978

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E2 - 11296

Decay of Giant Resonance States in Radiative Pion Capture by 1p Shell Nuclei

The decay of the giant resonance states excited in the radiative pion capture on the nuclei ^{9}Be, ^{11}B, ^{13}C and ^{14}N is considered in the shell model with intermediate coupling. It is shown that the excited states in the daughter nuclei (A-1, Z-1) are mainly populated by intermediate states with spin by two units larger than the spin of the target nuclei. Selected coincidence experiments are proposed.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1978

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1. *Introduction*

A specific feature of the radiative pion capture by atomic nuclei is the appearance of a broad maximum in the spectrum of hard γ quanta [1] which corresponds to the excitation of nuclear states in the region of the giant resonance. If one accepts the interpretation of resonance mechanism, this excitation is due to the transition of one nucleon to a neighbouring oscillator shell. In light nuclei and for stopped pions the elementary amplitude of the (π^-, γ) process with excitation of $1\hbar\omega$ states is dominated by the spin dipole term $(\sigma_1 \times Y_1)_K$ of rank $K = 0, 1, 2$. Hence, the number of partial transitions forming the resonance is rather large, and the resonance itself is broad. Additional spreading of the calculated strength is found by including $2\hbar\omega$ excitations which are mainly giverned by the spin-quadrupole operator $(\sigma_1 \times Y_2)_{K=1,2,3}$ (ref. [2,3]). This part as well as higher multipole components become important for heavier nuclei.

We have recently presented the shell model analysis of the (π^-, γ) reaction on a series of 1p shell nuclei [4-6]. The gross structure of available data [7] could be interpreted in terms of configurational splitting of final states with different symmetry character, and the shift of the main resonance peak with increasing mass number was explained in terms of the varying role of valence and hole excitation through the 1p shell. Spin predictions for dominant resonances obtained in these calculations could be understood in terms of the structure of the target ground states and of simple selection rules for the leading term of the transition amplitude.

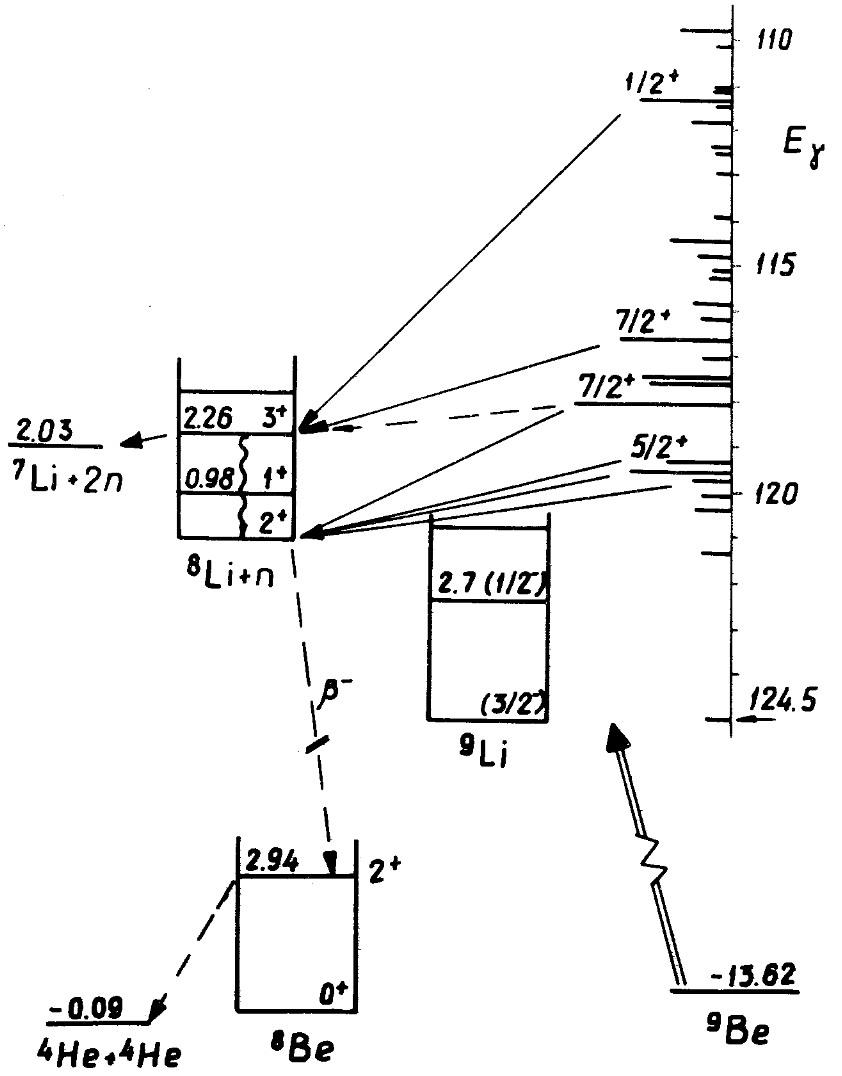

Fig. 1. The excitation scheme for the intermediate nucleus in the process ^{9}Be(π^-,γ) *and main decay channels of the giant resonance.*

For a more thorough check of the theory, the quantum numbers of strongly excited resonances should be known. This information is not obtained by comparing only the measured (π^-,γ) yields with the calculation. The spin assignment can in principle be deduced directly from the angular distributions of γ quanta from in-flight excitation of the specific resonance under consideration, or by measuring the angular correlation between the primary γ quantum (of selected energy) and the neutrons from the nucleon decay channels of the resonance. A more indirect way to get the resonance spin is to determine coincidence rates of the primary γ quanta with secondary particles from the decay of the resonance, e.g., by registrating monoenergetic neutrons from partial branches or the soft γ' quanta /8/ deexciting levels in the daughter nucleus:

$$\begin{array}{l}
\pi^- + (A,Z)_{J_0} \rightarrow (A,Z-1)^*_{J_i} + \gamma \\
\qquad\qquad\qquad \hookrightarrow (A-1,Z-1)^*_{J_f} + n \\
\qquad\qquad\qquad\qquad \hookrightarrow (A-1,Z-1) + \gamma'.
\end{array}$$

In this case the excitation spectrum of the intermediate nucleus $(A,Z-1)^*_{J_i}$ consists only of states which are genealogically coupled to the selected levels in the daughter nucleus $(A-1,Z-1)^*_{J_f}$, and their number, as a rule, is much smaller than the total number of states forming the resonance. The information on the intermediate spin J is then contained in the genealogy $(J_i \rightarrow J_f)$ and may be extracted from the coincidence rates. Experiments of this type have been performed with photonuclear reactions /9/ and provided details on the structure of the photogiant resonance /10/.

In this note we discuss the nucleon decay branches of (π^-,γ) resonances in the intermediate nuclei $A = 9$, 11, 13 and 14. As a rule, the prominent (π^-,γ) resonances have also rather selective neutron decay branches to the g.s. or low-excited levels in the daughter nucleus. For

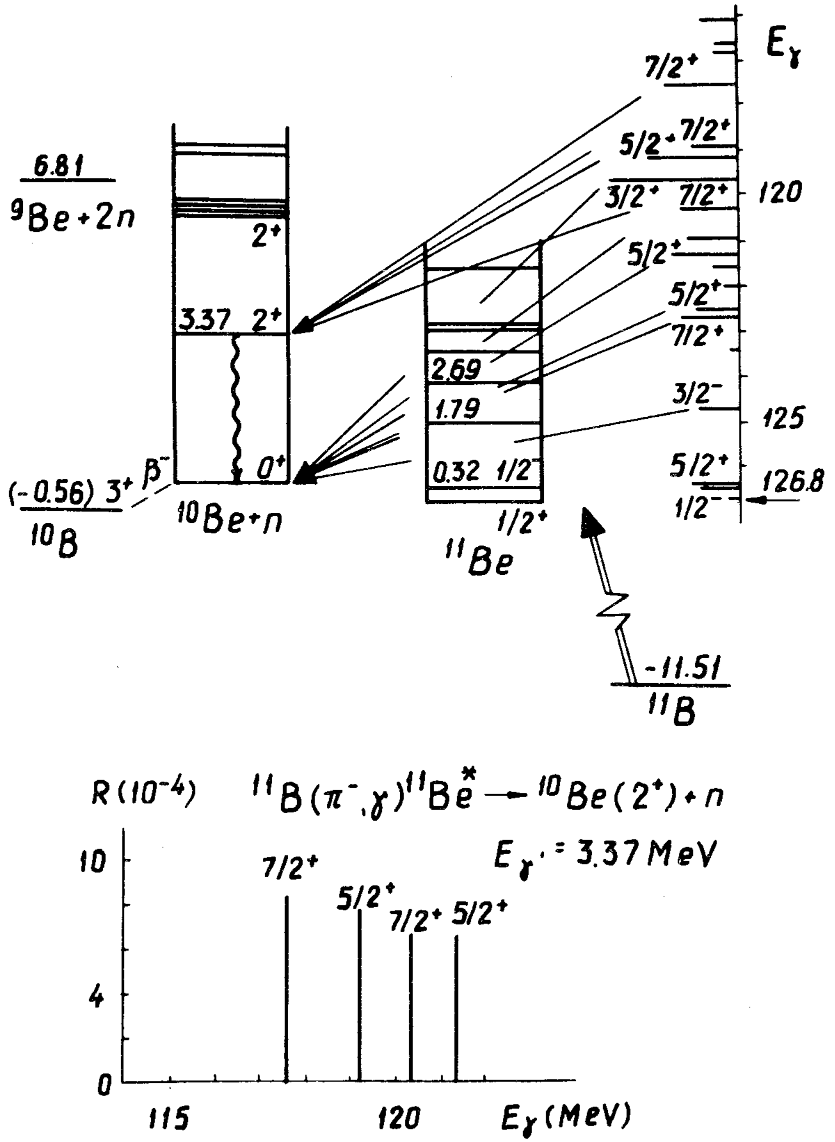

Fig. 2. The excitation scheme for the intermediate nucleus in $^{11}B(\pi^-,\gamma)$ reaction, main decay channels of the giant resonance and excitation spectrum of the nuclear system on coincidence with γ' transition $E_{\gamma'} = 3.37$ MeV.

the $A = 6$ and 7 cases there is no chance for $(\gamma\gamma')$ coincidences since the strongly fed excited levels in the $(A-1)$ system are unbound.

2. Results

The decay branches were estimated using the relations

$$\Gamma_{if} = 2\cdot\gamma_0^2\cdot k\cdot\sum_{n\ell j} P_\ell\, S(n\ell j),\quad \gamma_0^2 \propto \frac{h}{\mu a_c},$$

Γ_{if} being the partial width of level $i(A)$ to a level f in the nucleus $(A-1)$; k is the wave number of relative motion, P_ℓ and $S(n\ell j)$ being the penetration and spectroscopic factors; γ_0^2 —— reduced single-particle width, μ - reduced mass, a_c - channel radius. In calculating the branches $R_{if} = R_i\cdot\Gamma_{if}/\Gamma_i$ (R_i - population of level i, $\Gamma_i = \sum_f \Gamma_{if}$) the absolute normalization of the quantities S and γ_0^2 drops out.

a) $A = 9$

The giant resonance in the ^9Li system (cf. fig. of ref. /6/) decays mainly to the g.s. and excited 3^+ level in ^8Li. Among the predicted strong resonances ($5/2^+$, $E_x(^9Li) \simeq 5.5$ *MeV*; $7/2^+$, 7.0; $7/2^+$, 8.4; $1/2^+$, 13.7 *MeV*) the two lowest ones decay to the ^8Li g.s. with $S(d_{5/2})$ dominating, The other two resonances feed excited states,preferably the 3^+ level just above the threshold; this branch might be determined from the (nn) coincidence including the secondary monoenergetic neutron, or possibly from the $(\gamma\gamma')$ coincidence. The total activation of the bound levels in ^8Li could be determined through the β^- decay ($^8Li \to {}^8Be\,(2^+, 2.94) \to 2\alpha$) followed by α disintegration (see *fig.1*).

b) $A = 11$

Although the nuclear model adopted yields the main peak of the $^{11}B(\pi^-,\gamma)$ yield at too low excitation energy (cf. ref. /6/), it should tentatively provide the

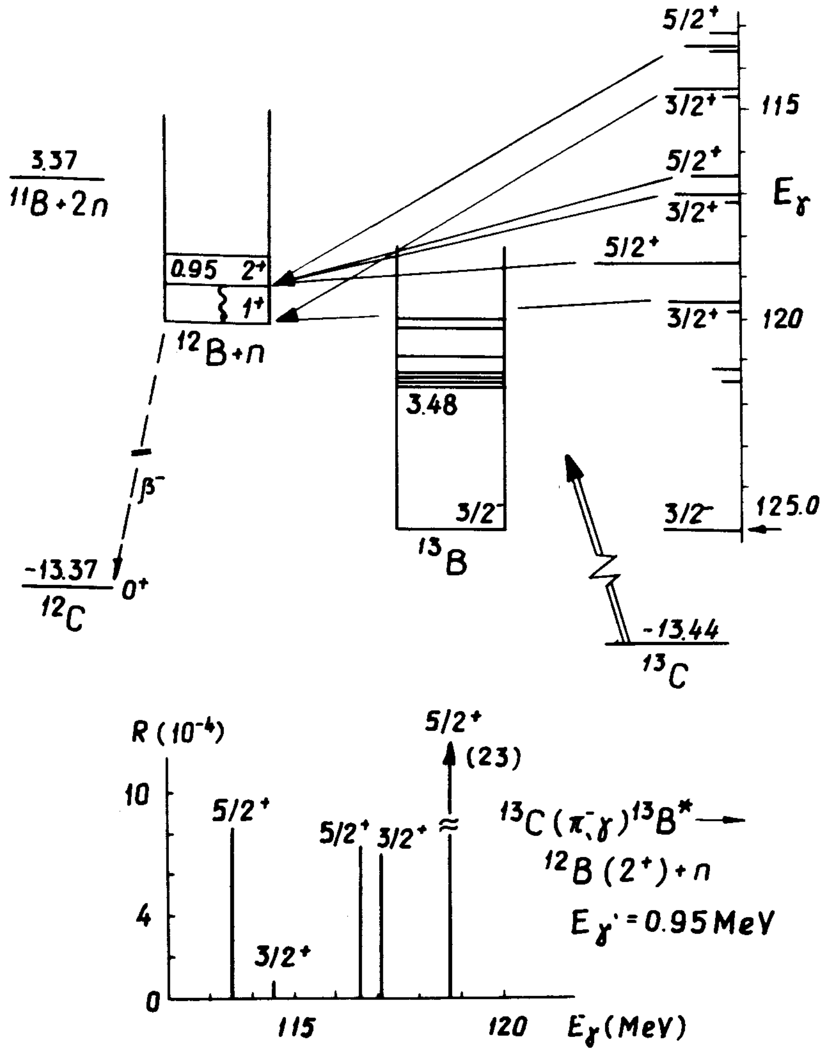

Fig. 3. The excitation scheme for the intermediate nucleus in $^{13}C(\pi^-,\gamma)$ *reaction, main decay channels of the giant resonance and excitation spectrum of the nuclear system in coincidence with* γ' *-transition* $E_{\gamma'} = 0.95$ *MeV.*

decay pattern of dominant lines. The resonance is expected to decay mainly to the g.s. and first excited state in ^{10}Be. Strong branches from $7/2^+$ and $5/2^+$ resonances predicted at $E_x(^{11}Be) \gtrsim 6$ *MeV* should dominantly feed the bound 2^+, 3.37 *MeV* level. The main peak ($3/2^+$) decays to the g.s. *Figure 2* shows the predicted coincidence spectrum with the 3.37 *MeV* deexcitation quant. The activation of bound levels cannot be measured because the β^+ decay is highly forbidden.

c) $A = 13$

As in the $A = 11 \rightarrow 10$ case, in the ^{12}B nucleus the lowest two levels will mainly be populated. The $\Delta J = 2$ resonances ($5/2^+$) should mainly feed the 2^+, 0.95 *MeV* level. *Figure 3* shows the predicted coincidence spectrum with the 0.95 *MeV* quant. The total activation of bound levels in ^{12}B might be measured vai the ^{12}B β^--decay.

d) $A = 14$

The $^{14}N(\pi^-,\gamma)$ reaction (cf. fig. 6 of ref. [6]) offers several possibilities for coincidence measurements. The two strong resonances 3^- and 2^+ below threshold could be selected by the deexcitation quanta (6.73 and 7.01 *MeV*). The strong 2^+ resonance just above threshold might be seen in the neutron spectrum ($E_n \approx 0.13$ *MeV*); the same is expected for the strong 2^- resonance which should decay to the ^{13}C g.s.

For the strong $\Delta J = 2$ resonances around $E_x \simeq 15$ *MeV* strong decay branches to the $3/2^-$, 3.68 *MeV* level are predicted, with $S(d_{3/2})$ dominating over $S(d_{5/2})$ by an order of magnitude. *Figure 4* shows the predicted branches to the $3/2^-$ level.

The 2^- resonances around $E_x \simeq 18$ *MeV* should preferably populate the $5/2^-$, 7.55 *MeV* level in ^{13}C; this yield could be determined either from the (nn) coincidence with the monoenergetic neutron or possibly from the γ' deexcitation, since the $5/2^-$ level should be quasistable against neutron emission because of the large orbital momentum transfer required ($\Delta\ell = 3$).

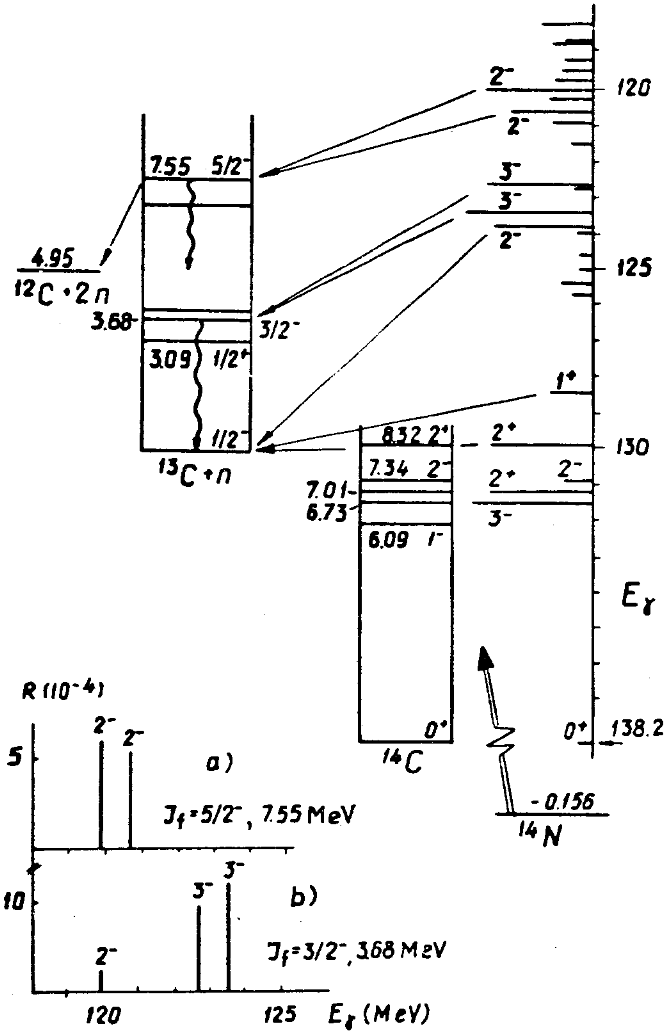

Fig. 4. The excitation scheme for the intermediate nucleus in $^{14}N(\pi^-,\gamma)$ reaction, main decay channels of the giant resonance and excitation spectrum of the nuclear system in coincidence with γ' transition a) $E_{\gamma'}$ = 3.68 MeV, b) $E_{\gamma'}$ = 7.55 MeV.

3. *Summary*

In all cases considered the excited states of daughter nuclei (A–1,Z–1) are mainly populated by resonance levels with spin J_i by two units larger than the g.s. spin J_0 of the target nucleus. In our opinion, the study of the yield of primary γ quanta in coincidence with soft γ' quanta, though being difficult, will provide information on the spin structure of giant resonances in the radiative pion capture.

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Received by Publishing Department
on January 31, 1978.