Fast-neutron excitation of levels with a large neutron width in the region of isobar-analog states

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Experimental data for the interaction of neutrons with Pb^{207}, which indicate that two neutron doorway states are excited in the Pb^{207} system at excitation energies of 23.95 ± 0.20 MeV and 24.50 ± 0.20 MeV, are presented.

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In earlier measurements of the total neutron cross sections for Pb^{207} and the cross sections for elastic scattering of neutrons by Pb[1], we observed a resonance effect at a neutron energy of about $E_n = 16.8$ MeV, which corresponds to the neutron doorway state of the $^{207}Pb + n$ system with an energy $\epsilon_x = 24.1$ MeV. This result was tentatively interpreted as the isobar-analog state (IAS) of a Pb^{208} nucleus. Weidenmüller pointed out a paradoxical consequence that follows from the data of Ref. 1—a very large elastic neutron width Γ_{n0} for the observed resonance. We repeated the experiments, increasing their accuracy and expanding the range of measurements. A tritium titanium target, which was bombarded by deuterons accelerated by a cascade generator, served as the neutron source. The energy resolution of the neutron beam was 120

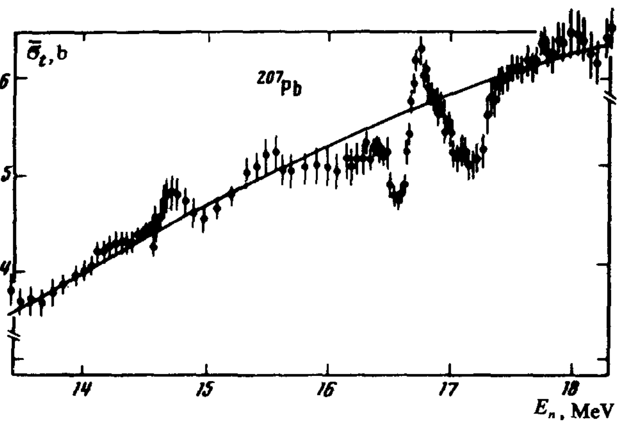

FIG. 1. Energy dependence of the weighted mean of the total neutron cross sections for Pb^{207} as a result of averaging over 100-keV energy interval.

keV on the average. The Pb^{207} samples were enriched from 82% to 91%. The variation of the total cross sections was measured with an accuracy of 0.6% on the average (at a point), and their absolute values were determined with an accuracy of at least 2%. The cross section for scattering by Pb was measured relative to the cross section of Bi (alternately with two scatterers) with an accuracy of about 3%. Such experimental setup further ensured the exclusion of systematic errors. The resonant behavior of the cross sections with energy was confirmed for Pb^{207} and determined more precisely. The effect in the interval $15.5 \leqslant E_n \leqslant 17.0$ MeV was represented earlier in the form of a peak on an almost energy-independent substrate. The measurements in a wider interval (see Fig. 1) showed that the cross section increases on the average, and, if it is approximated by choosing the optical—model parameters, we shall obtain the average dependence represented by the curve in Fig. 1. The resonance features appear as deviations from this curve in the form of two minima with a maximum between them. This is apparently consistent with Ref. 2, in which no resonances were observed, since under the conditions of this experiment the predicted effect of ± 0.06 b can lie within the error limits because of forward scattering of neutrons.

Our data[3] are well described by two similar resonances in the cross sections for Pb^{207} at $E_n = 16.65 \pm 0.20$ MeV and $E_n = 17.20 \pm 0.20$ MeV ($\epsilon_x = 23.9$ MeV and $\epsilon_x = 24.5$ MeV) with total widths $\Gamma = 190 \pm 40$ keV and by the ratio of elastic widths to total widths $g\frac{\Gamma_{n0}}{\Gamma} = 0.6 \pm 0.2$. The proton decay channel of the $Pb^{207} + n$ system was investigated by Belovitskiĭ *et al.*[4] in the same ϵ_x region. A smooth behavior of the cross section for (np) reaction was observed within 5% accuracy limits; this indicates that the Γ_p/Γ ratio for these resonances is small. In terms of their location, widths, and type of interference, the states observed by us are similar to two IAS of the Pb^{208} nucleus with spin and parity I^-.[5]

Levels with rather large $g\frac{\Gamma_n}{\Gamma}$ ratios have also been observed in other nuclei.[6–8]

TABLE I. Estimates of the probability of intense direct neutron transitions during excitation and decay of analog resonances.

Reaction channel	States	Resonance energy, MeV	Neutron width, keV	Total width, keV	Rel. $\frac{\Gamma_{no}}{\Gamma}$	Remarks
$Mg^{24} + n \rightarrow Mg^{25}$	5/2 +	0.475	0.013	0.014	0.93 ± 0.11	
	3/2 +	0.555	0.009	0.014	0.63 ± 0.16	
	1/2 +	1.567	4.2 ± 0.4	5.0 ± 0.2	0.85 ± 0.4	
$Si^{28} + n \rightarrow Si^{29}$	1/2 +	1.254	9.0 ± 0.9	9.0 ± 0.9	1.0 ± 0.2	
$Zr^{90} + n \rightarrow Zr^{91}$	9/2 +	5.63	—	—	0.2	
	3/2 −	5.72	—	—	0.2	
	5/2 −	6.15	—	—	0.2	
	7/2 −	6.35	—	—	0.2	Product $g\frac{\Gamma_{no}}{\Gamma}$
	5/2 +	6.48	—	—	0.2	
$Sb^{118} \rightarrow Sb^{117} + n$	0 +	4.49	4.66	32	0.15	
$Pb^{207} + n \rightarrow Pb^{208}$	(1−)	16.5	120 ± 40	200 ± 70	0.6 ± 0.3	
(data to be published)	(1 −)	17.2	120 ± 40	200 ± 70	0.6 ± 0.3	Product $g\frac{\Gamma_{no}}{\Gamma}$

The data for these levels, which are interpreted as the excitation of IAS by neutrons, are given in Table I along with some data of Guzhovskiĭ (see, for example, Ref. 9), which pertain to an indirect estimate of the direct neutron widths from a (pn) reaction, and our results for Pb^{207}. Since the neutron channel is the only open channel for Mg^{25} and Si^{29} nuclei, $\Gamma = \Gamma_{n0}$ (see Table I); note, however, the absolute widths, which are characteristic of the IAS in this region of nuclei. This indicates that the isospin selection rule has a small influence on the total width $\Gamma = \Gamma_{n0}$. The direct elastic width Γ_{n0} in the behavior Sb^{118} reaches 15% of Γ (see Table I), whereas the total direct width Γ_n for the IAS of an Mo^{94} nucleus reaches 34% (on the average). This set of nuclei indicates that the resonances with large direct neutron widths are observed near the closed shells or in target nuclei with a large neutron attachment energy; as the IAS they belong to the analogs of the excited states of parent nuclei. The direct Γ_n of Zr^{91} and Pb^{208} were calculated by Urin *et al.* (see, for example, Ref. 10). An estimate of the experimental values of $g\frac{\Gamma_{n0}}{\Gamma}$, which can be obtained for Zr^{91} from Ref. 6, is much larger than the theoretical estimate, and for Pb^{208} it is a factor of 1500 larger if the IAS is assumed to exist. In both cases the experiment shows that Γ_p is much smaller than Γ_{n0}.

The Pb^{208} nucleus was investigated at excitation energy of about 24 MeV in four types of experiments: our measurements in which Γ and $g\frac{\Gamma_{n0}}{\Gamma}$ were determined for the two resonances; the experiments on the $(e,e'p)$ and (γp) reactions,[5] which determine the ratio $2\Gamma_\gamma \Gamma_p/\Gamma = 0.5$ keV for the two unresolved levels that are close to our levels; σ_{np} measurements,[4] from which the restriction $g\frac{\Gamma_{n0}\Gamma_p}{\Gamma^2} \leqslant 3\times 10^{-3}$ follows; $\sigma_{\gamma,xn}$ data for Pb with a resolution of the order of 1 MeV. If the same levels are observed in our experiments and in the (γp) reaction, then the following estimates can be made: since $g\frac{\Gamma_{n0}}{\Gamma} \approx 0.6$ and $\Gamma \approx 190$ keV, $\Gamma_p \lesssim 1$ keV and $\Gamma_p/\Gamma \lesssim 5\times 10^{-3}$ (near the Zr^{91} resonances which are interpreted as IAS, $\Gamma_p/\Gamma \approx 10^{-2}$).[6] If we assume that $\Gamma_p \approx 1$ keV, then $\Gamma_\gamma \approx 50$ keV, which is identical to the single-particle estimate. Assuming that the IAS is excited and that $\Gamma_p/\Gamma \approx 0.75$–$1.00$, the authors[5] give the values $0.25 \leqslant \Gamma_\gamma \leqslant 0.35$ keV, which does not follow directly from the experiment. If Γ_γ is large, then a very strong resonance will appear in the 24 to 25-MeV energy region of γ-quanta in the cross section for (γn) reaction induced by Pb^{208}. This would lead to unrealistically large $\sigma_{\gamma n}$ values for a single-particle estimate of Γ_γ; however, an effect of the order of 200–300 mb cannot be completely ruled out if we take into account the accuracy of the available data. On the whole, however, it is hard to reconcile all these results by attributing them to the same levels. Another possible interpretation is that different fragments of particle-hole states appear in different reaction channels. These states (fragments) are rather close, and Γ_γ of a given fragment rather than the radiation width of a particle-hole state must be taken into account in estimating the width.

Thus, the neutron doorway states with large neutron widths and small probability of decay into a compound-nucleus state exist in the excitation energy region of heavy nuclei, where the IAS with small Γ_n and large Γ_p are assumed to be the only known type of doorway states. On the other hand, the isospin selection rule in many cases does not greatly suppress the neutron doorway channel as a result of excitation of the IAS, whereas the proton channel is severely reduced by the barrier and by neutron-escape competition (for example, because of the configuration peculiarities of the doorway and final states).

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