Study of the possibility of exciting the isobar-analog states in the ^{207}Pb(np) reaction

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The possibility of exciting the isobar-analog states (IAS) in the ^{207}Pb(np) reaction was investigated. No excitation of IAS was observed within the experimental error limits. The upper value of the excitation cross section of possible resonances is $\sigma_{np}^{R} \leqslant 0.6$ mb. The results are compared with the experimental data obtained elsewhere and with the calculation.

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A study of the excitation of isobar-analog states in isospin-forbidden reactions with neutrons is important for understanding its reaction mechanism and for determining the mechanism of isospin symmetry violation.

Two resonances at $E_n = 16.6$ MeV and $E_n = 17.2$ MeV were observed in Ref. 1 for the first time in the ^{208}Pb compound nucleus in the ^{207}Pb(nn) reaction. The total width $\Gamma = 200$ keV of the resonances is characteristic of IAS, but the elastic neutron width was found to be unusually large ($\Gamma_n = 120$ keV). There was no evidence of excitation of IAS in the ^{208}Pb(np) reaction,[2] whereas an excitation of several IAS with a typical width $\Gamma = 50$ keV and $\Gamma_n = 1.0$ keV was observed in ^{90}Zr(nn), (np).[3]

In an earlier investigation[4] we have observed IAS in a ^{207}Pb compound nucleus in the ^{206}Pb(np) reaction at neutron energies of 14.0 and 14.4 MeV and obtained $\Gamma = 150$ keV, $\Gamma^{\prime} = 0.06$ keV.

In this experiment we investigated the excitation of IAS in the ^{208}Pb compound nucleus in the ^{207}Pb(np) reaction using neutrons with $E_n = 15.3$–19.0 MeV. The neutron energy needed to excite the isobar-analog of the ground state of the ^{208}Tl parent nucleus is 15.6 MeV. The level scheme of ^{208}Tl nucleus is not known for excitation energies greater than 1 MeV.[5] Therefore, it is impossible to calculate the value of E_n for the corresponding analogs. It follows from the experimental data for neighboring nuclei that the total number of levels of the parent nucleus is more than 60 in the investigated energy range. Most of them have a simple, partially vacant structure.

The ^{207}Pb(np)Tl^{207} reaction with $Q = -0.7$ MeV was identified from the induced β activity. The residual ^{207}Tl nucleus is a pure β emitter with $E_{\beta_{\max}} = 1.4$ MeV and $T_{1/2} = 4.77$ min. Another possible reaction is ^{207}Pb ($n, pn + nd$)Tl^{206}, where Tl^{206} is a pure β emitter with $T_{1/2} = 4.3$ min. These reactions cannot be separated from the main reaction by using the activation method. It follows from Ref. 7, however, that they do not prevent the observation of IAS. [The (nd) reaction is doubly forbidden in isospin.] The enriched samples contained ^{207}Pb-79%, ^{208}Pb-18%, ^{206}Pb-3%; therefore, we measured the total activity associated with the ^{207}Pb($np + n,pn + nd$) + ^{208}Pb($np + n, pn + n\alpha$) reactions. Neutrons with an energy of 15–19 MeV were obtained in the T(dn)

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reaction in an EG-5 electrostatic generator by varying the deuteron energy from 0.8 MeV to 3 MeV and by placing the samples at angles of 10° and 50° with respect to the deuteron beam. A Ti-T target with a thickness of 0.6–0.8 mg/cm^2 was used. Accelerator calibration and target thickness were checked from the threshold of the (pn) reaction. The energy spread of the neutron beam was about 200 keV and the energy range for the measurements was 50–150 KeV.

The 30×50-mm, 0.4-mm-thick ^{207}Pb plates used as samples were mounted at a distance of 5 cm from the target with the narrow side facing the neutron source. The irradiation time was 6 minutes. The activity of the samples was measured using test setups comprised of two SBT-10 counters with a 30-cm^2 effective area that were mounted with the windows facing each other (4π geometry) and placed in a 5-cm thick lead cylinder Surrounded by a blanket of MS-6 counters connected in an anticoincidence circuit to reduce the background. The counters operated in the Geiger mode.

The primary neutron beam was monitored by activating one of the ^{27}Al, ^{28}Si, ^{138}Ba samples which were placed at a 120° angle to the deuteron beam. For this angle the neutron energy (13.4 MeV) does not depend on the deuteron energy. The monitor samples had a $T_{\frac{1}{2}}$ close to 5 minutes and a large reaction cross section. In the case of ^{138}Ba monitor (99.8% enrichment) we used the ^{138}Ba$(n, 2n)$ Ba^{137m} reaction with $Q = -8.61$ MeV. The activity of ^{137m}Ba isomer that emitted γ rays with $E_\gamma = 0.66$ MeV was measured by a Ge-Li spectrometer. The aluminum and silicon monitors turned out to be more convenient. The ^{27}Al(np) and ^{28}Si(np) reactions were used. Their β activity was measured by using the same apparatus as that for the ^{207}Pb samples. In addition, they provided a higher statistical accuracy. A good agreement between the results was observed when different monitors were used.

Since the ^{207}Pb samples contained an impurity of the ^{208}Pb isotope, we have measured the energy behavior of the activities in ^{208}Pb (98% enrichment) for neutrons

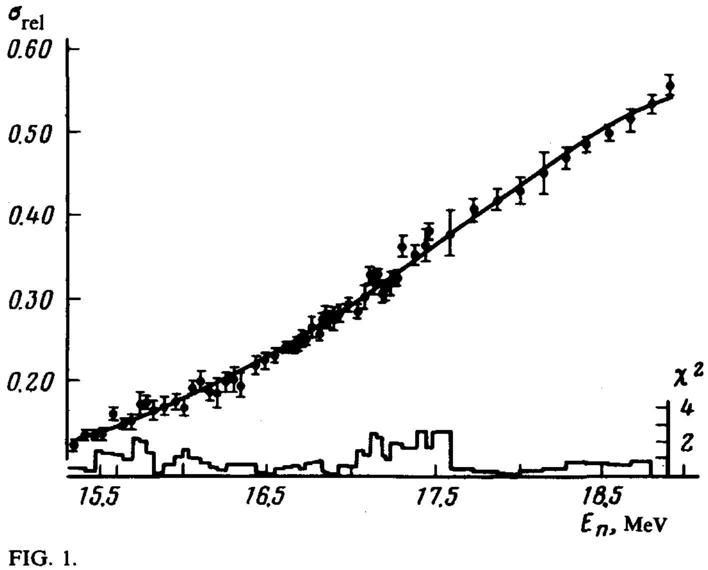

FIG. 1.

with energies of 16.4–17.7 MeV. The deviations from a smooth dependence were within the experimental error limits, and the ^{208}Pb contribution to the ^{207}Pb activity did not exceed 25%.

Several series of measurements of the excitation function of the ^{207}Pb(np) reaction were made. The results of the measurements are shown in Fig. 1 (which also shows the distributions of the average χ^2 components). The total experimental error for a confidence coefficient of 0.7 is about 5% on the average. A curve was drawn through the experimental points using the least-squares method, and the deviations of the experimental points from the curve were calculated by the χ^2 method (see Fig. 1). Special attention was focused on the interval $E_n = 16.40$–17.20 MeV. An evaluation of all the values gives $\chi^2 = 0.8$–1.4, which indicates that there are no anomalies. A plotting of the χ^2 components, which were averaged over a sliding interval of three points in all the measurements, shows that there are spikes with a squared amplitude of 1 to 3. This does not allow us to draw any conclusions about the presence of resonances in the entire investigated interval.

The estimate of the upper value of the resonance cross section is $\sigma_{np}^R = 0.1\,\sigma_b$ (two errors), where σ_b is the background cross section. On the basis of Ref. 6 and our measurements, and with allowance for the ^{208}Pb activity, we obtain $\sigma_b = 6$ mb and $\sigma_{np}^R \leqslant 0.6$ mb. Using Breit-Wigner formula for a single resonance and the value $0.1 < \Gamma_p/\Gamma < 0.7$ for the IAS in the neighborhood of lead,[7] we obtain an elastic neutron width $\Gamma_n^{\uparrow} < 10$ keV. A calculation[8] gives $\Gamma_n^{\uparrow} = 0.002$ keV. A value of $\Gamma_n^{\uparrow} = 120$ keV, obtained in Ref. 1, is an order of magnitude larger than ours and larger than the $\Gamma_n^{\uparrow}$ values obtained in other experiments.[9]

The results of our experiments can be reconciled with those of Ref. 1, where the resonances with $\sigma_t^R = 150$ mb in the same compound nucleus were observed in the total and differential cross sections for neutrons with an energy of 16.6 and 17.2 MeV (excitation energy of 24.0 and 24.6 MeV), if $\sigma_{np}^R = \sigma_t^R \Gamma_p/\Gamma$, where $\Gamma_p/\Gamma < 3 \times 10^{-3}$ or $\Gamma_n/\Gamma_p > 3 \times 10^2$.

Dahman *et al.*[7] observed the IAS ($I^\pi = 1^-$) in the ^{208}Pb($\gamma p + \gamma,pn$) and ^{208}Pb($e,e'p$) reactions at $E_* = 25$ MeV. These resonances cannot be observed in the ^{207}Pb(np) reaction; this may be due to a smaller effect and the fact that many IAS, which cannot be observed because of their overlapping, can be excited in the (np) reaction, in contrast to (γp).

Let us now compare the results of the three experiments discussed above with σ_γ--the total γ-ray absorption cross section in ^{208}Pb.[10] We shall assume that the resonances in the reactions with neutrons[1] and γ-rays are identical. The resonance cross section of IAS excitation in the (γp) reaction is $\sigma_{\gamma p}^R = 3$ mb.[7] Using $\Gamma_n/\Gamma > 3 \times 10^2$ obtained from the first two experiments, we can calculate the resonance cross section for the ^{208}Pb(γn) reaction:$\sigma_{\gamma p}^R = 3.3 \times 10^2 = 900$ mb. As follows from Ref. 10, no resonances were observed in σ_γ in this region of γ-ray energies, although $\sigma_\gamma < 50$ mb is constant in a wide range of E_γ.

It is likely that the resonances in the experiments with neutrons and γ rays belong to different, highly excited states of the ^{208}Pb nucleus. The 700-keV shift of the resonance energies in both experiments is an additional indication in favor of this interpretation. This evidence and the unusually large $\Gamma_n^{\uparrow}$ allows us to assume that the resonances in Ref. 1 can be attributed to the formation of other doorway states at high excitation energies.

In conclusion, we should mention that the resonance neutron energies[1] are close to the proton energies as a result of excitation of the $d_{5/2}$ and $S_{1/2}$ IAS, which are strongly excited in the (*pp*) reaction of lead isotopes.[11]

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