Investigation of the possibility of excitation of isobar-analog states in the ^{208}Pb(*np*) reaction

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An experiment was performed by the activation method for neutrons with an energy of 16.5–19.5 MeV. A resonance excitation cross section of ≤0.2 mb is obtained for the IAS and an elastic neutron width $\Gamma_n^{\uparrow} \leqslant 3.0$ keV. The results are compared with the calculation and with the experimental data of other authors.

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This paper is a continuation of a series of papers dealing with the investigation of the possibility of excitation of isobar-analog states (AIS) in the (*np*) reactions in lead isotopes in the neutron energy region 12–20 MeV. Previously, we had observed the excitation of IAS in the ^{206}Pb(*np*) reaction[1] at $E_n = 14.0$ MeV and 14.4 MeV and had investigated the possibility of their excitation in the ^{207}Pb(*np*) reaction.[2] The excitation of IAS was not observed in the ^{207}Pb(*np*) reaction, and only the upper limit of the cross section $\sigma_{np}^R \leqslant 0.6$ mb for possible resonances was obtained.

We have investigated the excitation of IAS by neutrons in the ^{209}Pb compound nucleus in the ^{208}Pb(*np*) reaction. In a similar investigation[3] no IAS excitation was observed in the ^{209}Pb nucleus. However, the behavior of the cross section for the (*np*) reaction in Ref. 4 differed drastically from the calculation[4] and from the subsequent experiment.[5] This stimulated us to repeat the measurements.

The energy necessary for excitation of IAS by neutrons was calculated analogously to that in Ref. 1, and it is equal to 18 MeV for the IAS of the ground state of ^{209}Tl($J^{\pi} = \frac{1}{2}^+$) and 18.32 MeV for the IAS of the first excited state. The accuracy of determining the neutron energy was $\pm$ 100 keV.

The ^{208}Pb(*np*) ^{208}Tl reaction was identified from the induced γ activity. The residual ^{208}Tl nucleus is a β and γ emitter with $T_{1/2} = 3.1$ min, since all the β transitions occur in the first 5 excited levels of the ^{208}Pb nucleus, which produces a large number of γ lines.

The enriched ^{208}Pb samples contained 97.8% ^{208}Pb, 1.4% ^{207}Pb, 0.7% ^{206}Pb, and 0.1% ^{204}Pb. The reaction products of ^{207}Pb and ^{206}Pb isotopes, which are β emitters, produce no interference.

The neutrons with an energy of 16.5–19.5 MeV were obtained in the $T(d,n)$ reaction in the EG-5 electrostatic accelerator of the Institute for Nuclear Research of the USSR Academy of Sciences by varying the deuteron energy from 0.8 to 3 MeV. A Ti-T target with a thickness of 0.6–0.8 mg/cm^2 was used. The calibration of the accelerator and the thickness of the targets were checked against the threshold of the (*pn*) reaction. The energy spread of the beam was about 200 keV and the energy increment was 40–70 keV.

The ^{208}Pb samples were $25 \times 30 \times 1.6$-mm^3 plates. During irradiation the samples were mounted in the vertical plane perpendicularly to the deuteron beam. The distance from the samples to the target was 8 cm and the irradiation time was 6 min. The γ activity of the samples was measured in a Ge-Li or scintillation NaI spectrometer with a truncation of the γ-ray spectrum below 200 keV.

The neutron flux was monitored by measuring by γ activity of the ^{137m}Ba isomer formed as a result of the $^{138}Ba(n,2n)$ reaction. The characteristics of the reaction and isomer are: $Q = -8.61$ MeV, $\sigma = 1020$ mb, $T_{1/2} = 2.56$ min, and $E_\gamma = 0.66$ MeV. The ^{138}Ba samples (99.8% enriched) in the form of $BaCO_3$ powder in 25-mm-diam polyethylene capsules were mounted at an angle of 120° to the deuteron beam at a distance of 10 cm from the target. The neutron energy at this angle is almost independent of the deuteron energy.

The excitation function of the $^{208}Pb(np)$ reaction was measured in several series. The results of the measurements are shown in Fig. 1 (the components of the χ^2 histogram are also shown there). The experimental results are given with a total rms error of about 2.5% for a 0.7 confidence coefficient. A curve was drawn through all the data points using the least-squares method (LSM) and the deviations of the experimental points from this curve were estimated by the χ^2 method.

The experimental data are poorly described by low-degree ($n = 3,4$) polynomials. A satisfactory description can be obtained only for a polynomial of degree $n = 7$ ($\chi^2 = 1.5$ as opposed to $\chi^2 = 2.5$ for $n = 4$). The points of the 17.5–18.3-MeV interval give the largest contribution to the χ^2 sum. After excluding this interval, the remaining data were well described by the polynomial of degree $n = 2$. Interpolation of this polynomial in the 17.5–18.3-MeV region shows that the points of this interval are systematically higher than the interpolated curve. The deviation of experimental data from this curve, which was estimated by the χ^2 method and averaged over a three-point, sliding interval to smooth out the spikes, showed that two smeared (distributed)

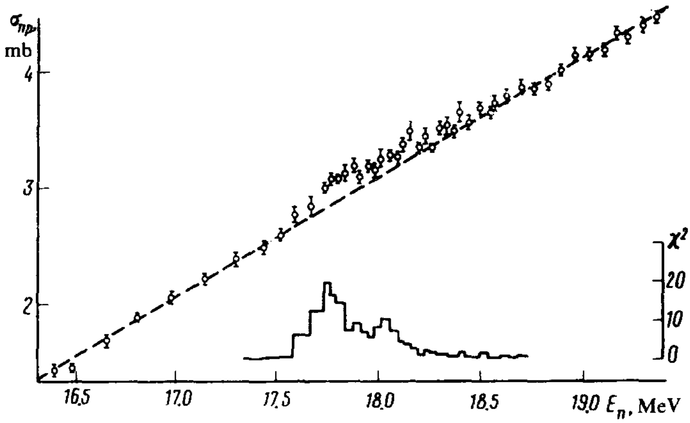

FIG. 1.

TABLE I.

Isotope-target	J^π of the target nucleus	J^π of IAS	E_n for excited IAS, MeV	$\Gamma_n^\uparrow$ exp., keV	$\Gamma_n^\uparrow$ calc., keV
^{206}Pb	0^+	$11/2^-$ $5/2^+$	13.9 14.3	0.46	0.2
^{207}Pb	$1/2^-$	1^-	16.9	< 10.0	0.002
^{208}Pb	0^+	$1/2^+$ $3/2^+$	17.9 18.2	2.9	0.02

peaks are present at neutron energies of 17.8 and 18.1 MeV. These anomalies may be due to excitation of two IAS—the ground state and the first excited level of a ^{209}Tl nucleus.

The maximum amplitude of the deviation is equal to $7 \pm 2.5\%$ for the first peak and $3.5 \pm 2.0\%$ for the second peak (as a percentage of the base value) for a confidence coefficient of 0.7. The peaks are not separated because of the large energy smearing; this prevents a more accurate determination of the characteristics of these resonances.

In the second analysis we used the data for σ_{np} calculated according to the exciton model which were, normalized experimentally at 16.4 MeV. The χ^2 components, which were computed relative to the calculated points, have a structure similar to that described above.

The width $\Gamma_n^\uparrow$ can be estimated from these data. According to Ref. 5, the cross section of the (np) reaction for $E_n = 18$ MeV is equal to 3 mb. Thus, the resonance cross section is $\sigma_{np}^R = 0.07\ \sigma_{np}^{\text{back}} = 0.21$ mb. We can see from the distribution of the χ^2 components that the total width of the two maxima is 450 keV, i.e., we can assume that $\Gamma = 200$ keV for one maximum, which is typical for the IAS in the region of heavy nuclei. Using $0.1 < \Gamma_p/\Gamma < 0.7$ and the Breit-Wigner formula for a single resonance: $\sigma_{np}^R = 4\pi\lambda\!\!\!^{-2} \dfrac{\Gamma_p \Gamma_n}{\Gamma^2}$, we obtain a $\Gamma_n^\uparrow$ that lies within the limits $0.4 < \Gamma_n^\uparrow < 3$ keV. A theoretical calculation[6] gives a noticeably smaller value $\Gamma_n^\uparrow = 0.02$ keV for this quantity.

We now compare the experimental data and the theoretical calculations on IAS excitation in (np) reactions for three lead isotopes. It follows from the experimental data that the IAS excitation is observed in the even isotope-targets and not observed in the odd isotope-target. This may be partly due to a smaller magnitude of the effect in the odd isotope, as follows from the theoretical calculations, and also to the large number of excited levels of the parent nucleus of the ^{209}Tl analog and inadequate energy resolution. For these reasons, the IAS either do not occur or have a much smaller value of σ_{np}^R. The experimental and theoretical widths $\Gamma_n^\uparrow$ for the investigated IAS are listed in Table I.

The "$\Gamma_n^{\uparrow}$ exp." column lists the results obtained on the assumption that[7] $\Gamma_p/\Gamma = 0.1$. Since no IAS excitations were observed for ^{207}Pb in the (np) reaction, we took the double-squared error, which is twice as large as that for the other two experiments, as the upper limit of the resonance cross section.

Despite the inadequate accuracy of the experiment, a comparison of the experimental and theoretical values of $\Gamma_n^{\uparrow}$ indicates an appreciable discrepancy between theory and experiment. Further theoretical and experimental investigations are necessary to explain these discrepancies and to understand the IAS excitation mechanism in isospin-forbidden due to the action of neutrons.

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