Excitation of isobaric analog states by neutrons in the Pb^{207} nucleus

G. E. Belovitskiĭ and O. S. Presnyak
Institute of Nuclear Research, USSR Academy of Sciences

(Submitted 24 April 1979)
Pis'ma Zh. Eksp. Teor. Fiz. **29**, No. 12, 791–793 (20 June 1979)

The excitation of isobaric analog states (IAS) in the isospin forbidden Pb^{206} (n,p) reaction was observed. The experimental data are compared with the calculation.

PACS numbers: 24.30.Eb, 25.40.Fq, 27.80. + w

Investigation of the isospin-forbidden reactions with excitation of the IAS, in particular the neutron-induced reactions makes it possible to determine the reaction mechanism and the mechanism of the isospin symmetry breaking. Robson[1] pointed out that the decay of the IAS via the neutron channel can occur if we assume that the $T_>$ state mixes with the background $T_<$ state. The neutron-induced excitation of the IAS investigated in Refs. 2 and 3. The observed resonance effects were 1–2% as compared with the cross section outside of the resonance.

In this paper we investigate for the first time the excitation of the IAS in the compound nucleus in the Pb^{206} (n, p) reaction. The nuetron energy needed to excite the IAS was determined from the foumula: $E_n^{cm} = \Delta E_c - Q_{np} - B_n$, where $\Delta E_c = (1.430\ \bar{Z}/A^{1/3} - 0.992)$ MeV is the Coulomb shift of the isobaric pair, $\bar{Z}$ is the average charge of the isobaric pair, Q_{np} is the reaction energy of the nucleus in question, and B_n is the neutron binding energy in the parent nucleus. The values Q_{np} and B_n were taken from Refs. 4 and 5. The neutron energy was determined with an accuracy of ± 100 keV. Two IAS are possible at $E_n = 13.9$ and 14.3 MeV in the accessible to us energy range for Pb^{206}.

The Pb^{206} (n, p)Tl^{206} reaction was detemined from the induced β activity. The residual Tl^{206} nucleus was a pure β-emitter with $E_{\beta\max} = 1.5$ MeV $T_{1/2} = 4.2$ min. The neutrons were obtained in the $T(d, n)$ reaction. The energy of the accelerated deuterons was 300 keV. The diameter of the beam was 2 mm. The neutron energy was varied by placing the samples at different angles to the deuteron beam with an energy step of 50 to 100 keV. The energy resolution was better than 150 keV. The measurements were carried out using a target arrangement, which allowed to omit corrections for the absorption. The Pb^{206} samples, which were highly enriched with Pb^{206} (90%), Pb^{207} (7%) and Pb^{208} (3%), were 30×50-mm plates 0.8 mm in thickness. During irradiation they were placed with the narrow side facing the neutron source. The samples were placed 10 cm from the target. The irradiation time was 8 minutes. The activity of the samples was measured by an apparatus consisting of two end-window counters mounted with the windows facing each other (4π geometry). The counters worked in the Geiger mode. The background of the apparatus was 1% of the measured activity.

A comparative method, described in Ref. 6, was used to measure the energy dependence. One of the samples was placed at different angles α and the other—the

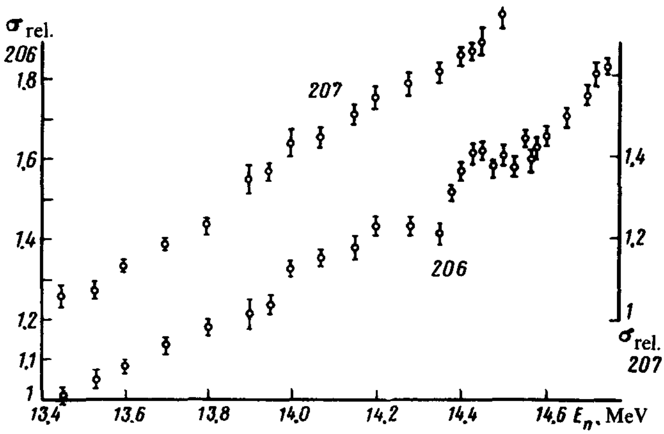

FIG. 1. Energy dependence of the cross sections for the Pb^{206} (n, p) reaction-lower points (left-hand scale) and for the Pb^{207} (n, p) reaction—upper points (right-hand scale).

monitor—was placed at a fixed angle $\alpha = 160°$ ($E_n = 13.4$ MeV). This method of measuring σ_{np} does not require a stable beam or a special monitoring of the neutron flux.

The results of measuring the excitation function of the Pb^{206} (n, p) and Pb^{207} (n, p) reactions, which was carried out for comparison, are shown in Fig. 1. The cross section of the Pb^{206} (n, p) reaction at $E_n = 13.4$ MeV is equal to 1.2 mb.[6] The errors indicated in the graph, which represent the total experimental error, comprise 2–2.5% for the confidence coefficient of 0.7. The plot for Pb^{206} deviates from the regular σ_{np} dependence at $E_n = 13.9$–14.5 MeV.

The evaluation of the measurements of the excitation function according to the χ^2 method give $\chi^2 = 1.2$. However, the distribution of the components comprising the χ^2 sum shows that the largest contribution comes from the points in the interval where the anomalies are observed. The curve plotted according to the method of least squares (MLS) is weighted down by these points, and the obtained deviations are too low (Fig. 2). A more correct evaluation is one in which the smooth curve is drawn according to the MLS, ignoring the anomalous interval. The χ^2-calculations of the deviations of the experimental points from this curve are shown in Fig. 2 (dashed histogram).

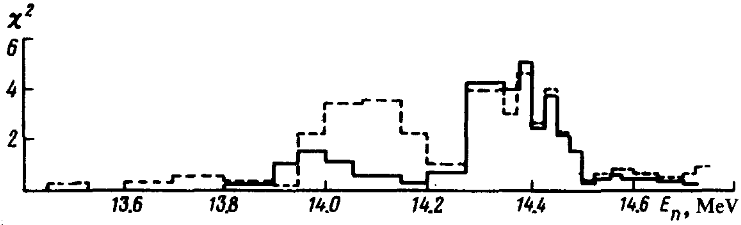

FIG. 2. The χ^2 components calculated for the curve drawn through all the points by using the method of least squares (solid histogram) and for the curve drawn without taking into account the anomalous ($E_n = 13.9$–14.55) interval (dashed histogram).

It can be seen in Fig. 2 that in the neutron energy range of 13.9 to 14.55 MeV the excitation function of the Pb^{206} (n, p) reaction has anomalous deviations from the smooth dependence. An analogous statistical analysis of the results of the measurements of Pb^{207} (n, p) showed that the excitation function of the Pb^{207} (n, p) reaction does not have such deviations.

The anomalous behavior of the cross section of Pb^{206} (n, p) can possibly be attributed to the excitation of two isobaric analog states at $E_n = 14.0$ and 14.4 MeV. We give the following arguments in favor of this assumption: 1) the energy of the resonances and their relative position on the energy scale are in good agreement with the calculation; 2) the experimental widths of the resonances are ≈ 200 keV, which is characteristic of the IAS in the region of heavy nuclei.

Let us compare the experimental characteristics of the isobaric analog resonance at $E_n = 14.4$ MeV $(2d_{5/2})$ with the theoretical prediction. The experiment gives the upper value $\Delta\sigma_{np} = 0.12$ mb for the cross section above the background and the resonance width of $\Gamma \approx 150$ keV. For nuclei in the region of lead we can see from the experiments on excitation of the IAS by protons that $0.1 \leqslant \Gamma_p/\Gamma \leqslant 0.7$. Guba *et al.*[7] calculated for Pb^{206} within the limits of the shell model the elastic neutron width for the direct decay of the IAS-$\Gamma_n^{\uparrow}$ and obtained the value of 0.08 keV. If the values Γ_p/Γ and $\Gamma_n^{\uparrow}$ are substituted in the resonance Breit-Wigner formula, then we obtain $0.05 \leqslant \Delta\sigma_{np} \leqslant 0.3$ mb. These theoretical values are in satisfactory agreement with the expeimental values.

In conclusion, we note that there is evidence (see Fig. 2) that the IAS are excited at $E_n = 14.0$ keV $(1h_{11/2})$. The upper values are $\Delta\sigma_{np} \approx 0.1$ mb and $\Gamma \approx 200$ keV. Additional measurements are needed in order to obtain more exact quantitative characteristics of this IAS. Such calculations of $\Gamma_n^{\uparrow}$ for this IAS at present are not available.

[1]D. Robson, Phys. Rev. **B137**, 535 (1965).

[2]B.A. Benetskiĭ, V.V. Nefedov, I.M. Frank, and I.V. Shtranikh, Kratk, Soobshch. Fiz. (Brief Communications in Physics), No. 3, **75**, 1972; Yad. Fiz. **17**, 21 (1973) [Sov. J. Nucl. Phys. **17**, 10 (1973)].

[3]O. Hicks and A. Legge, J. Phys. A. Math. Nucl. Gen. 7, 3 (1974); D. Long and S. Onega, Can. J. Phys. **52**, 7 (1974); H. Weigtman *et al.*, Phys. Rev. **C14**, 1324 (1976).

[4]Landolt-Börnstein, New Series, I/5a, 1972.

[5]V.A. Kravtsov, Massy atomov i énergii svyazi yader (Atomic Masses and Nuclear Binding Energies), Atomizdat, M., 1974.

[6]G.E. Belovitskiĭ, O.S. Presnyak, and L.V. Sukhov, Neĭtronnaya fizika, (Neutron Physics), Part 4, p. 209, 1976, Materialy 3ĭ Vsesoyuznoĭ konferentsii po neĭtronnoĭ fizike (Proc. III All-Union Conf. on Neutron Physics), Kiev, 1975; Kratk. Soobshch. Fiz. (Brief Communications in Physics), FIAN, No. 6, 16, 1974.

[7]V.G. Guba, D.F. Zaretskiĭ, and M.G. Urin, Pis'ma Zh. Eksp. Teor. Fiz. **21**, 386 (1975) [JETP Lett. **21**, 176 (1975)].