Regular spin splitting of cross sections for nuclear reactions induced by 14-MeV neutrons

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A regular spin splitting of the nuclear reaction cross sections, a newly observed effect, has been established on the basis of the data on the cross sections for (n,p), (n,α), and (n,d) reactions at even tin isotopes with $A = 112$–122. These reaction cross sections were measured at neutron energy 14.6 ± 0.2 MeV.

Experimental results[1] show that at neutron energy of ~ 14 MeV the cross sections of (n,p) and (n,α) reactions at nuclei of different isotopes of a single chemical element decrease with increasing mass number of the isotope (the Levkovskiĭ rule). The quantum-mechanical characteristics of nuclei, the reaction products, have been disregarded, however, in the relevant experimental dependences and in the formulas[2] which are used to describe them. We will attempt to determine the relationship between the cross sections of the reactions induced by 14-MeV neutrons and the spin and parity of the residual nucleus on the basis of a systematic experimental study of the cross sections of

TABLE I. Cross sections measured for the first time.

Reaction and half-life of product nucleus			I^π (Ref. 4)	σ, mb
$^{114}Sn(n, p)$	^{114}In	(71.9s)	1^+	105 ± 30
$^{114}Sn(n, p)$	^{114}In	(49.51d)	5^+	23 ± 15
$^{116}Sn(n, p)$	^{116}In	(2.16s)	8^-	4.0 ± 2.4
$^{118}Sn(n, p)$	^{118}In	(8.5s)	8^-	0.9 ± 0.1
$^{120}Sn(n, p)$	^{120}In	(47.3s)	8^-	0.27 ± 0.08
$^{122}Sn(n, p)$	^{122}In	(1.5s)	1^+	20 ± 10
$^{122}Sn(n, p)$	^{122}In	(10.3s)	$(4,5^+)$	0.8 ± 0.2
$^{122}Sn(n, p)$	^{122}In	(10.8s)	(8^-)	0.18 ± 0.06
$^{120}Sn(n, \alpha)$	^{117}Cd	(2.4h)	$1/2^+$	0.21 ± 0.05
$^{120}Sn(n, \alpha)$	^{117}Cd	(3.4h)	$11/2^-$	0.15 ± 0.04
$^{122}Sn(n, \alpha)$	^{119}Cd	(2.7m)	$1/2^+$	0.15 ± 0.04
$^{122}Sn(n, \alpha)$	^{119}Cd	(1.9m)	$11/2^-$	0.032 ± 0.008
$^{112}Sn(n, d)$	^{111}In	(7.6m)	$1/2^-$	2.7 ± 0.5
$^{120}Sn(n, d)$	^{119}In	(2.1m)	$9/2^+$	0.20 ± 0.05

(n,p), (n,α), and (n,d) reactions involving even tin isotopes with $A = 112$–122.

The experiments were carried out by an activation method using the Khar'kov University's NG-150M neutron generator which produced (14.6 ± 0.2)-MeV neutrons. A tube conveyer was used to deliver the irradiated samples to the γ-ray spectrometer. The energy resolution of the Ge(Li) detector ($\sim$50-cm^3 volume) of this spectrometer was $\sim$3.5 keV for ^{60}Co. We used samples of natural and enriched tin (the enrichment level is given in parentheses): ^{112}Sn (98.9%), ^{114}Sn (71.1%), ^{116}Sn (97.8%), ^{118}Sn (95.63%), ^{120}Sn (99.6%), and ^{122}Sn (96.0%). All of the cross sections were measured relative to the cross sections for (n,p) reactions at ^{27}Al and ^{28}Si, using the same method.[3]

The cross sections measured for the first time are presented in Table I. Additional data on these cross sections, published elsewhere,[5,6] are shown in Figs. 1–3. These figures show the partial cross sections for the production of a product nucleus with the values of $T_{1/2}$ and I^π indicated in Table I. Curve C in Figs. 1 and 2 was plotted from the data of Ref. 2 on the cross sections predicted theoretically using systematics. Curves 1^+, 5^+, 8^-, $1/2^+$, $11/2^-$, $9/2^+$, and $1/2^-$ were drawn through the points corresponding in Figs. 1–3 to the partial cross sections for the reactions in which the residual nuclei are produced with spins and parities indicated on these curves.

These figures show that in the case of the (n,p), (n,α), and (n,d) reactions with

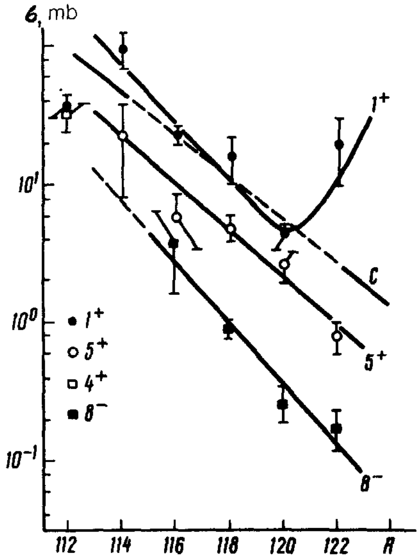

FIG. 1. Cross sections of (n,p) reactions at even tin isotopes vs their mass number A. The estimated experimental data for $A = 116$ and 120, taken from Ref. 2, are shown on the 1^+ curve; the remaining are our data. The estimated experimental data for $A = 116$–120 are presented in Ref. 2; for this reason, a segment of curve C is a dashed curve.

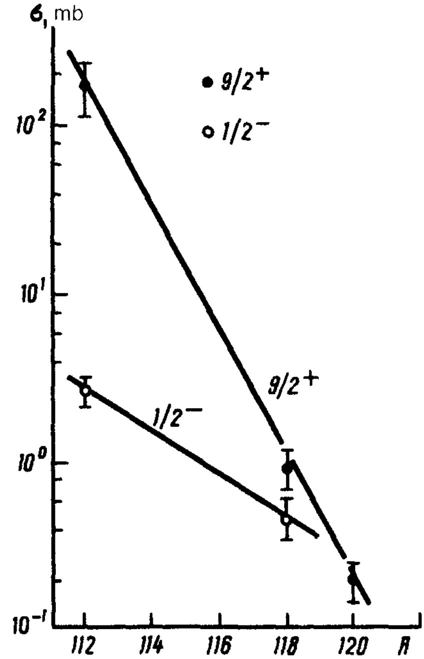

FIG. 2. Cross sections for (n,α) reactions at even tin isotopes vs their mass number A. An estimated experimental cross section for $A = 118$ is given in Ref. 2, as shown by the dashed segment of curve C.

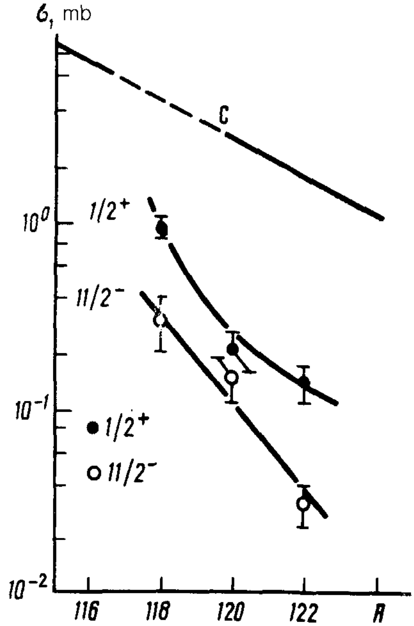

FIG. 3. Cross sections for (n,d) reactions at even tin isotopes vs the mass number A of the target nucleus. Here the cross section for the (n,d) reaction is the total cross section of the (n,d), (n,np), and (n,pn) reactions which were not distinguished in the activation experiments.

even tin isotopes the cross sections for nuclei of different isotopes decrease in a complicated way as their mass number increases. But when the curves are shown graphically, the corresponding points lie on various smooth curves, each of which corresponds to a definite spin and parity of the product nucleus. We thus conclude that there is a regular spin splitting of the cross sections. The curve of the cross sections vs the mass number of the target nucleus, which conforms with the Levkovskiĭ rule,[1] splits into two or more similar curves, each of which corresponds to the formation of a product nucleus in a state with a definite spin and parity of the residual nucleus.

The regular spin splitting refines considerably the Levkovskiĭ rule by explicitly taking into account the spin and parity of the product nucleus which is produced in the reaction, and identifies new methods of studying the spin-dependent effects in nuclear reactions induced by fast neutrons.

The study of the regular spin splitting may also improve considerably the prediction of cross sections which have not yet been measured. This contribution would be of considerable value for applications (as can be seen in Figs. 1 and 2, in several cases the predicted cross sections differ from the measured cross sections by more than an order of magnitude, suggesting that the methods used for theoretical predictions must be improved).

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