CROSS SECTIONS FOR (n, p) REACTIONS ON TIN ISOTOPES FOR 14.5 MeV NEUTRONS

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The cross sections for the (n, p)-reaction on the tin isotopes $Sn^{112, 116, 118, 119, 120}$ are measured by the activation method. The experimental values do not confirm the semi-empirical law of decrease of the (n, p) cross sections with growth of mass number obtained by Gardner [1]. In order to make the theory consistent with the experimental data it is necessary to take into account shell effects in nuclei and the presence of strongly competing reaction channels on going from isotope to isotope.

DURING the last two years great interest has been shown in the laws observed in the cross sections of reactions induced by 14-MeV neutrons in separated isotopes of many elements. It was observed, for example, that the cross section of reactions of the type (n, p) and (n, np) for any isotope of a given element constitutes approximately one-half of the cross section for the preceding isotope of the same element [1]: This tendency in the experimental cross sections has led to an attempt by some workers to derive semi-empirical formulas for the description of the experimental results.

For the (n, p) reactions, the most effective relations were those proposed by Levkovskiĭ [2] and Gardner [1]. Recently all the experimentally known cross sections of the reactions (n, p), (n, np), (n, 2n) and others were compared with the expressions obtained [1,2], and, as a rule, some qualitative and quantitative agreement was observed to some degree or another. This success has induced Gardner to try to find some physically justified basis for the empirical formulas of [1]. Using methods of statistical physics and elements of the theory of compound-nucleus formation, Gardner [1,3] obtained for the cross sections a relation which also takes into account the nucleon pairing energy. It turned out [3] that an account of the nucleon pairing energy improves the agreement with experiment.

Later on Gove and Nakasima [4] used a statistical model with a more rigorous approach to the problem of neutron reactions. All these attempts do not lead to satisfactory agreement for nuclei with closed shells or nearly closed shells.

In our earlier work [5] we noticed that the deviation of the experimental cross section on Ni^{64} from linearity is not accidental. Moreover, we believe that excessive involvement with the Gardner method can lead to the undesirable and incorrect opinion that the compound-nucleus mechanism alone can explain the experimental results over a wide range of mass numbers. There are already in existence numerous data [6] on nuclear reactions with both charged particles and neutrons, which show that the influence of the individual features of the nuclei, the mechanism of the reaction, the character of the competing channels, and particularly shell effects in the nucleus, are quite considerable. We therefore have undertaken to measure the cross sections of the (n, p) and (n, np) reactions on nuclei with closed shells, particularly tin isotopes.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The research method employed by us was already described in detail earlier [7].

In the present investigation we used free thin metallic tin foils with the following percentage enrichment: Sn^{112} – 66.2, Sn^{116} – 92.8, Sn^{118} – 88.4, Sn^{119} – 74.8, and Sn^{120} – 99.1. The energy of the bombarding neutrons was close to 14.5 MeV.

Our experimental results are listed in a table and are compared with data that follow from the relation proposed in [1,2].

The absolute values of the cross sections were checked by measuring the yield of calibration reactions. The cross section of the $Cu^{63}(n, 2n)Cu^{62}$ ($\tau = 9.7$ min, $Q = -10.9$ MeV), which is equal to 552 mb [8], was used as a basis.

In addition, control measurements were made on the cross sections of the following reactions:

Isotope and reaction	Half-life	Experimental cross section, mb	Cross sections (mb) calculated	
			after Levkovskiĭ[2]	after Gardner [1]
$Sn^{112}(n, p)In^{112}$	18.1 min	$10.0^{+1.2}_{-2.6}$	36.4	1792
$Sn^{116}(n, p)In^{116}$	5.4 min	5.4 ± 1.5	11.2	112
$Sn^{118}(n, p)In^{118}$	4.5 min	11.7 ± 2.5	6.47	28
$Sn^{119}(n, p)In^{119m}$	17.5 min	11.1 ± 2.5	4.9	14
$Sn^{119}(n, p)In^{119g} + Sn^{119}(n, np)In^{118}$	4.0 min	10.6 ± 2.8	—	—
$Sn^{120}(n, p)In^{120}$	51 sec	4.6 ± 1.2	3.8*	7

*The calculations were based on Gardner's work.[1]

$Al^{27}(n, p)Mg^{27}$ ($\tau = 9.7$ min, $Q = 1.81$ MeV),

$\sigma = 73$ mb,

$Ag^{107}(n, 2n)Ag^{106}$ ($\tau = 25$ min, $Q = -9.5$ MeV),

$\sigma = 520$ mb,

$Ag^{109}(n, 2n)Ag^{108}$ ($\tau = 2.3$ min, $Q = -9.3$ MeV),

$\sigma = 580$ mb.

In all these cases the cross sections measured by us coincided, within the limits of experimental error, with the literature data [9].

It must be noted, however, that the cross section we obtained for the (n, p) reaction on Sn^{112} may be somewhat too high (owing to the experimental conditions on this target), so that we give an asymmetrical value for the error.

When Sn^{119} is bombarded with 14.5-MeV neutrons, the result may be either In^{118} from the (n, np) reaction, or In^{119g} and In^{119m} from the (n. p) reaction. The half-life of the ground state of In^{119} is 2.3 min [10], and that of In^{118} is 4.5 min [11]. It is impossible to separate the 2.3-minute activity from the 4.5-minute one. The half life resulting from ten independent measurements is 4.0 ± 0.5 min. We therefore give the summary cross section for the reactions $Sn^{119}(n, p)In^{119g} + Sn^{119}(n, np)In^{118}$ and separately the cross section for the isomer state. The cross section of the (n, p) reactions on Sn^{120} coincide within the limits of experimental error with the results published by Gardner [1]. For the remaining elements, these measurements have been made here for the first time.

As can be seen from the table, the experimental cross sections are closer to Levkovskiĭ's rules, but no decrease in the cross sections with increasing mass number is observed. We do not make a comparison here with the paper of Gardner and Poularikas [3], since not all the masses of the indium isotopes are known, but this last paper leads to results that are approximately intermediate between those of Gardner and Levkovskiĭ.

Thus, none of the laws proposed in [1-3] is suitable for the (n, p) reactions on tin isotopes. It is not surprising that no satisfactory agreement is observed between the measured cross sections of the (n, p) cross sections and the theoretical ones calculated on the basis of the compound-nucleus mechanism alone [1,3,4], since for tin, which has nine stable isotopes, the compound-nucleus process predominates for light isotopes and the direct processes for heavy ones [12,6]. It is probable that tin will not be an exception among the other nuclei with closed nucleon shells.

It will apparently become possible to explain reliably the law governing the variation of the cross sections of reactions with neutrons with the mass number only with the aid of detailed experimental information on the angular and energy distributions of the products of the neutron reactions and on the intensity ratios of the different competing reaction channels over a wide range of mass numbers.

The results of research in this direction will be published by us in the nearest future.

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