TOTAL CROSS SECTIONS FOR INTERACTION BETWEEN FAST NEUTRONS AND TIN ISOTOPES

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The total cross sections for interactions of 14.2-MeV neutrons with $Sn^{116-120}$, Sn^{122}, and Sn^{124} were measured. The accuracy of the measurements was ± 1%. It is found that the cross section does not vary in a monotonic fashion. An attempt is made to relate the mass number dependence of the cross section to the shell structure of the nucleus.

DURING the past few years, the total cross sections, the absorption cross sections, and the differential cross sections for elastic scattering of nucleons on atomic nuclei have been measured in a number of experiments. The optical-model parameters for the nuclear potential were determined from the results of these experiments. The general features of a number of phenomena involving a broad group of nuclei are well described by the optical model. This model describes all nuclei by a single set of parameters and does not take into account the individual peculiarities of the nuclei; therefore it does not claim to give precise agreement with experiment. In this connection, the investigation of the cross sections for interactions between neutrons and different isotopes of the same element is of interest, since in this case it can be expected that the specific properties of the nucleus will be more readily disclosed.

In fact, experiments on elastic scattering of protons show considerable change in the behavior of the differential cross section for elastic scattering from isotope to isotope. Thus far, no experiments designed to compare the cross sections for the interaction of fast neutrons with different isotopes of the same element have been reported. In the present experiment, we measured the total cross sections for the interaction of 14.2-MeV neutrons with seven isotopes of tin: $Sn^{116-120,122,124}$ We chose tin for this study since, first, it is the element with the largest number of stable isotopes, and second, the structure of the tin nuclei is known from the work of Kisslinger and Sorenson.[1]

DESCRIPTION OF THE EXPERIMENT

Since it is expected on the basis of the optical model that the total cross section varies slightly from isotope to isotope, then, in order to investigate the dependence of the cross section on the mass number, an accuracy of at least 1% is needed. A high accuracy is made difficult by the fact that the measurements have to be made with small quantities of substance. On the one hand, this leads to a need for a high stability of operation of the measuring equipment over a long period of time, and on the other hand, it is necessary to completely eliminate the background effects from scattered neutrons and γ rays.

In the present experiment, in which the total cross sections were measured, we determined the fraction of the neutron beam passing through a sample of known thickness. A well-collimated neutron beam was obtained with the aid of the αn-coincidence technique described in detail earlier.[2] We obtained 14.2-MeV neutrons from the reaction $T(d,n)He^4$. The angular spread of the collimated neutron beam was ±40′; the angle subtended by the detector was ±60′.

The samples of separated tin isotopes were in the shape of cylinders of diameter 9.5 mm and weight ~ 1000 mg; the height of the cylinder for a given isotope was constant to an accuracy of ± 0.1%. Particular attention was paid to ensuring that the angle between the axis of the collimated neutron beam and the plane of the sample base was exactly the same for all isotopes. Since the scatterers were of small size, it was necessary to know exactly the position in space of the neutron beam; for this purpose, the deuteron beam bombarding the tritium-zirconium target was limited by a diaphragm with a 3-mm opening. The measurements were reduced to the determination of the αn-coincidence counting rate with and without the sample in the neutron beam.

This method made it possible to completely eliminate background effects from scattered neutrons and γ rays; the fluctuations of the randomcoincidence counting rates were negligible in comparison with the change in the counting rates of the αn coincidences resulting from the interactions of neutrons with the sample. The utilization of the monoenergetic group of α particles made it possible to improve the stability of operation of the equipment; moreover, the α channel was a reliable monitor during the measurements.

During the measurements, however, we observed slow changes in the αn-coincidence counting rate. They occurred as a result of a steady contamination of the tritium-zirconium target, which led to a decreased effective energy of the deuterons and, consequently, to a change in the emission angles of the neutrons and α particles. Despite this, owing to the diaphragming of the deuteron beam, part of the beam impinged on the diaphragm, in which the $d(d,n)He^3$ and $d(d,p)T$ reactions occurred. The products of these reactions were also recorded in the α channel, which served as a monitor; they constituted a few percent of the α-particle counts and depended on the focusing of the deuteron beam on the target. The effect of these sources of instability was considerably reduced by means of rapid measurements (12—13 sec) with the scatterer and the empty mounting.

For each isotope, we carried out several thousand cycles of measurements, with and without the sample in the neutron beam. We carefully checked the symmetry of operation of the arrangement and showed that with the required accuracy of measurement the fluctuations of the αn-coincidence counting rate followed a normal distribution.

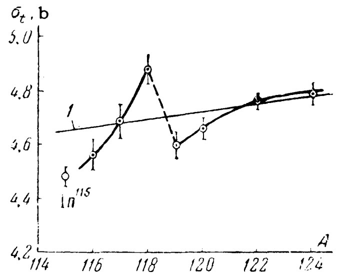
The value of the total cross section for neutron interactions was determined from the relation

$$\sigma_t = -\frac{\pi d^2 A \sin\varphi}{4WN_A} \ln\frac{N_p}{N_0},$$

where σ_t is the total cross section for the scattering of neutrons on a given isotope, d is the sample diameter, A is the mass number of the isotope, φ is the angle between the axis of the neutron beam and the plane of the scatterer, N_A is Avogadro's number, W is the sample weight, N_p and N_0 are the measured counting rates of αn coincidences with and without the sample in the beam.

DISCUSSION OF RESULTS

The figure shows the results of the measurements for the total cross sections of the interaction of neutrons with isotopes of tin and In^{115}, which has the same number of neutrons as Sn^{116}, but one proton less; the errors shown for the total cross sections are equal to one standard deviation; the errors in the determination of the number of atoms per 1 cm^2 did not exceed ± 0.05%. No corrections were introduced for the finite size of the neutron detector since, for the angular dimensions indicated above, the values of the corrections were considerably less than the measurement errors.



Dependence of the total cross section on the isotope mass number. The total cross section for In^{115} is shown for comparison; the remaining points refer to tin isotopes. Curve 1 represents the theoretical dependence of the cross section on the mass number A given by Luk'yanov et al.[5]

The dependence of the total cross section on the mass number, as shown in the figure, indicates an appreciable decrease in the value of σ_t for Sn^{119} and Sn^{120} in comparison with Sn^{118}; for isotopes of mass number $116 \le A \le 118$ and $119 \le A \le 124$, the cross section increases monotonically with the mass number. The nonmonotonicity in the behavior of the cross section, which is the most interesting result of our experiment, should be related, in the terminology of the optical model, to a nonmonotonic change in the single-particle potential. This, in turn, can be a consequence of the change in the nuclear structure for the tin isotopes connected with the inclusion of new single-particle states as the number of neutrons increases.

The tin isotopes have a filled proton shell (Z = 50); the number of neutrons outside the filled shell (N = 50) varies from 16 to 24. According to the single-particle model, in the region $50 \le N \le 82$ the neutron subshells $d_{5/2}$, $g_{1/2}$, $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ become filled. The sequence was taken from Nilsson.[3] Within the framework of this model, for $116 \le A \le 124$ in the case of tin the states $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ become filled, where the isotopes Sn^{116} and Sn^{120} should have the filled subshells $s_{1/2}$ and $d_{3/2}$, respectively.

The dependence of the total cross section on the mass number shown in the figure indicates a decrease in the value of the cross section for Sn^{120} in comparison with Sn^{118}; there is also a steep drop in the cross section curve from Sn^{118} to Sn^{116}; as in the case of Sn^{120}, the latter has a filled subshell. The fact that the jump in the cross section curve takes place not at Sn^{120} but at Sn^{119} can reflect the fact that Sn^{119} also has a filled subshell $d_{3/2}$ and one neutron in the $s_{1/2}$ state. This can occur here if the pairing energy for the $d_{3/2}$ subshell is greater than for the $s_{1/2}$ subshell, so that for Sn^{117} and Sn^{119} the unpaired neutron is in the $s_{1/2}$ state. This scheme of filling the neutron subshell is in agreement with the available experimental data on the spins and parities of the ground and first excited states of odd isotopes of tin.

In the work of Kisslinger and Sorenson,[1] in which the paired interaction was taken into account, the ground states of even-even nuclei are characterized by the quantities V_{lj}^2, indicative of the degree of filling of the corresponding state. From this viewpoint, for even-even isotopes one should speak not of the filling of some given subshell, but of an increase in the contribution of a given single-particle state. Cohen and Price[4] determined the values of V_{lj}^2 for even isotopes directly from the experimental data on the (d, p) and (d, t) reactions in tin isotopes. The results of their work also show that the population of the $h_{11/2}$ state sharply rises between Sn^{120} and Sn^{122}.

Although it is impossible to indicate which parameter in the optical-model potential determines the jump in the total cross section, the foregoing considerations suggest that the change in the cross section is related to specific changes in the nuclear structure.

In conclusion, the authors consider it their pleasant duty to express their gratitude to D. A. Varshalovich for taking part in discussion of the results of the present work; the authors also thank V. V. Vasil'ev for aid in the preparation of the equipment and in the measurements.

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[1] L. S. Kisslinger and R. A. Sorenson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd., **32**, No. 9 (1961).

[2] Yu. V. Dukarevich and A. N. Dyumin, PTÉ **5**, 34 (1961).

[3] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 16 (1955).

[4] B. L. Cohen and R. E. Price, Phys. Rev. **121**, 1441 (1961).

[5] Luk'yanov, Orlov, and Turovtsev, JETP **41**, 1634 (1961), Soviet Phys. JETP **14**, 1161 (1962).

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