ON CONTRADICTORY RESULTS OF MEASUREMENT OF THE (γ, n)*-REACTION CROSS SECTION FOR LEAD*

M. M. DOROSH, A. M. PARLAG, V. A. SHKODA-UL'YANOV, and L. A. SHABALINA

Uzhgorod State University

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The experimental results of measurement of yields in high- and medium-Z elements in the low energy region are not in agreement with the results of calculations performed on the basis of the Belen'kiĭ-Tamm cascade theory. An experiment was carried out with the aim of measuring the (γ, n) cross section in lead irradiated by bremsstrahlung, since the published data on the cross sections of some elements, including lead, are contradictory. The cross section obtained at the maximum is 0.65 b and is equal to the cross section for monochromatic γ-quanta. Comparison of the photoneutron yield calculated with the cross section thus obtained and the experimental data of Grizhko et al.[8] confirms the discrepancy between theory and experiment.

FROM the published data[1-3] on the measurement of the cross sections of photoneutron reactions for such elements as Pb, I, Ta and some others it is clear that the results of these measurements differ from each other quite radically, by 100% and more. In the case of lead, for example, this difference can be seen in the data of Montalbetti et al.[1] and Toms and Stephens[2] (see Fig. 1, curves 1 and 4). From the results of Gomonaĭ et al.[4] it would follow that the obtained yield confirms the results of [2]. However, a more thorough analysis of these results has shown that it is wrong to conclude on the basis of [2,4] that the values of the cross section of the (γ, n) reaction on lead are correct. For a final determination of the true cross section of the (γ, n) reaction in lead, we have measured this cross section on the 25 MeV betatron of the Uzhgorod University. The data known at the start of the measurements on the (γ, n) reaction cross section in lead are given in Fig. 1 (curves 1 and 4) and, as can be seen from the figure, differ by approximately a factor of 2. At the same time, for many other elements, the results obtained by different workers are in good agreement. For example, the results of measurements of the cross section for copper, obtained by different authors and by different methods, differ from one another by not more than 15–20%. Consequently many authors frequently use copper as a standard for measurements of the (γ, n) reaction cross section.

Our measurements were made on a 25 MeV betatron with a tungsten target. The system for monitoring the maximum energy of the accelerated electrons ensured stability of the γ-quantum energy with accuracy on the order of 30 keV. The neutrons were recorded with a setup analogous to that described in [3]. From 1 to 3 SNMO-5 neutron counters were placed in a paraffin tube measuring $73 \times 73 \times 80$ cm, with a 4×5 cm axial channel for the investigated samples. The counters were located 12.8 cm from the channel axis. The photo-

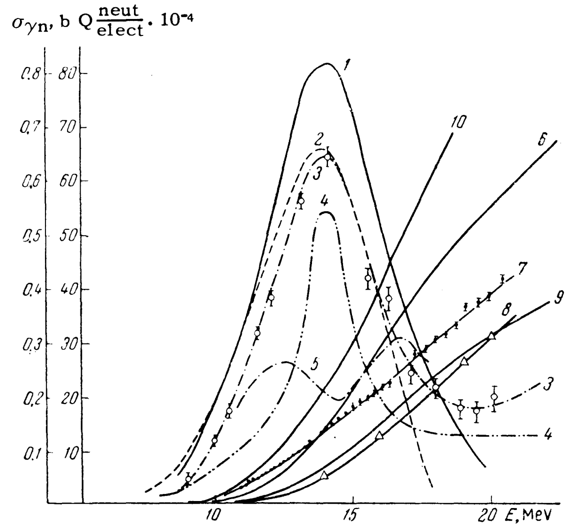

FIG. 1. Cross section of (γ, n) reaction in lead and photoneutron yield curves from an infinitely thick lead sample under the action of electrons. The ordinates on the left show the cross section of the (γ, n) reaction in barns, and on the right the absolute yield of neutrons in neutron/electron units; curve 2 shows the cross section of the (γ, n) reaction in lead, obtained in the present paper and calculated from the yield curve of Fig. 2.

neutrons were registered between the betatron pulses, with a delay of 30 microseconds following the γ-quantum pulse and a registration time of 900 microseconds. The correction for the missed pulses prior to the start of registration was 15%; the statistical error in the counting of the pulses was 3%, while in the region near threshold the error was 5–8%. The γ-quantum flux was measured with a thick-wall aluminum ionization chamber, described by Flowers et al.[5]. Along with measuring the photoneutrons from the lead, the yield from copper and bismuth was also measured. Figure 2 shows the results of measurements of the yield of photoneutrons from lead. The experimental points on the plot are mean values of 6 or 7 measurements, and these measurement data differ by not more than 4%. The photoneutron yield curves were also measured several times at intervals of 2–3 months. The results of these several series of measurements differed likewise by not more than 4%. The efficiency of photoneutron registration was determined by several neutron standard sources (Po–Be), and also by measurement of the yield of photoneutrons from the copper. The activity of the standard neutron source was known accurate to ±10%.

The excitation function of the photoneutron reactions was calculated for lead from the curve showing the yield of photoneutrons from lead (Fig. 2), by the "photon difference" method[6]. The Schiff bremsstrahlung spectrum was used in the calculation, normalized to a current of 1 microampere in the ionization chamber. As can be seen from Fig. 1, our cross section of the photoneutron reactions from lead is closer to the results of Montalbetti et al.[1] After our data and cross sections were obtained, Miller et al.[7] reported a measurement of the cross sections of photoneutron reactions with monochromatic γ quanta for several elements, including lead. These results agree well with our data (see Fig. 1, curve 3). The accuracy of our cross section can be estimated at ±18%, and near threshold at ±20–25%. The cross section errors in [7] are even smaller, since a monochromatic beam was used rather than a bremsstrahlung γ-quantum spectrum; the accuracy is on the order of 10%, whereas the discrepancy between theory and experiment is characterized by a factor of 2, which is clearly beyond the limits of experimental error. Consequently, we can conclude from the foregoing that the data of [2] (Fig. 1, curve 4) are much too low.

The organization of the experiment described here was decided upon from the following considerations: Grizhko et al.[8] measured the yield of

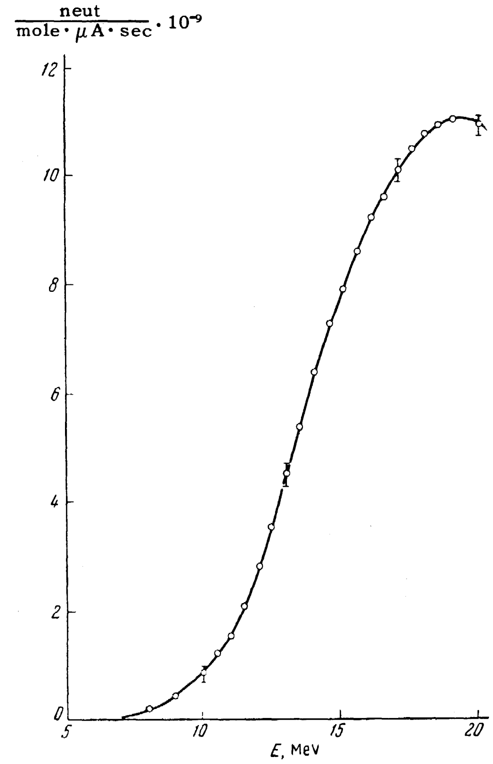

FIG. 2. Yield curve of photoneutrons from lead induced by bremsstrahlung.

photoneutrons from a practically infinitely thick sample of lead as a function of the energy of the incident monoenergetic electrons. The experimental points were the result of 5–7 measurements with a statistical error of ±2%, and were plotted every 150- 400 keV. On the other hand, even long before these experiments, in order to ascertain the necessary energy and electron-beam intensity intervals, calculations were made of the photoneutron yield from lead with different energy intervals. The calculated yield was then again used to obtain the initial cross section, by the method described in [9]. To this end, a spread of 2–3% was introduced into the photoneutron yield curves. Such calculations have made it clear that under fully realistic requirements with respect to the energy intervals, the intervals of intensity of the electron beam, and the accuracy with which the photoneutron yield is to be determined, it is possible to attain by means of the calculation of the excitation function in accordance with [9] an accuracy which is not worse than yielded by the method of the "photon difference" when working with thin samples. Consequently, since the results of analogous calculations are of interest also for several other problems[10,11], we were able, when solving the corresponding direct and inverse problems, to verify many times the correctness of this conclusion. After setting up the experiment[8] and carrying out the corresponding calculation[12], the results of which are shown in Fig. 1 (curve 5), it was found that when the yield of photoneutrons from lead is calculated by means of the cross section of the (γ, n) reaction given in [2], the calculated yield (Fig. 1, curve 9), obtained with the aid of the Belen'kiĭ-Tamm equilibrium spectrum, is located between the independent experimental determinations of the yields as given in [8,13], i.e., between curves 7 and 8. On the other hand, the calculation of the yield by means of another value known at that time for the cross section of the (γ, n) reaction for lead[1] (Fig. 1, curve 10) lead to the conclusion that the yield is highly overvalued, as follows from a comparison of the calculated and experimentally measured yields in [8,13]. This conclusion was subsequently verified only in part. It remained unclear why attempts to calculate the cross section of the (γ, n) reaction for lead from the experimental data [8], using the yield curves obtained in different manners, gave, within the limits of experimental scatter, a reproducible result but did not give the well known variation of the excitation function of the (γ, n) reaction [12] (see Fig. 1, curve 5). This raised the suspicion that the Belen'kiĭ-Tamm equilibrium spectrum is apparently not accurate in this region of energies for the heavy elements, and this leads to a strong distortion of the universally known course of the cross section of the (γ, n) reaction in the giant resonance region. However, in order to confirm this conclusion, it was extremely desirable to measure, with the maximum attainable accuracy, the cross section of the (γ, n) reaction in lead. As was already mentioned above, such measurements were carried out on the 25-MeV betatron, and also, independently of this work, using monochromatic γ quanta, in [7].

The calculation of the yield of the photoneutrons from lead (Fig. 1, curve 6), carried out using the Belen'kiĭ-Tamm equilibrium spectrum over the (γ, n) reaction cross section for lead from the present work and from the work of Miller et al.[7], and a comparison with the experimental data of [8,13] indicates that in this case the equilibrium spectrum of Belen'kiĭ-Tamm greatly distorts the cross section of the (γ, n) reaction in lead both in form and in absolute magnitude. The reasons for the observed discrepancies between the cascade theory and experiment are thus explained.

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