CROSS SECTION OF PHOTONEUTRON REACTIONS ON Ca^{40}

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Fig. 1

Figure 1: Fig. 1

Abstract

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CROSS SECTION OF PHOTONEUTRON REACTIONS ON Ca^{40}

Experimental procedure. On the synchrotron of the A. F. Ioffe Physico-Technical Institute of the Academy of Sciences of the USSR, a study was carried out of the total cross section of photoneutron reactions on the Ca^{40} nucleus in the range from the threshold of the γn reaction (15.62 MeV) to 50 MeV. Directly in the experiment, the yields of photoneutrons were measured as a function of the maximum energy of the bremsstrahlung spectrum of the γ radiation, $E_{\gamma\,\mathrm{max}}$, with a registration interval of 1 MeV. For this purpose the method of counting preliminarily slowed-down neutrons with BF_3 counters was used ([1]). During irradiation a calcium target of natural isotopic composition (97% Ca^{40}), 19.5 g/cm^2 thick, was used.

The statistical accuracy of the experimental points of the yield curve, taking into account the accuracy of background measurements, was within 0.3–1.0% for the giant-resonance region. At higher energies $E_{\gamma\,\mathrm{max}}$, the root-mean-square error decreased to 0.15%. The background level in the energy region above the giant resonance was within 4–5% of the total neutron count, increasing to 10% when the energy was reduced to 18–19 MeV. The accuracy of the absolute measurements of the cross sections depended mainly on the accuracy with which the neutron detection efficiency was determined, and was within 10–12%.

Fig. 1

Experimental results. The results of the measurements are presented in Fig. 1. The histogram in the lower part of the figure reflects the dependence of the cross section of the observed reactions on E_γ. It was obtained from the measured yield curve by a known method ([2]), directly, without any preliminary smoothing. The dependence of the integral cross section of reactions with neutron emission on E_γ (open circles) was obtained by successive summation of the values of the differential cross sections. The errors indicated in both cases characterize only the statistical accuracy of the experiment.

Through the points of the integral dependence, a smooth curve was drawn "by eye." Such a procedure in the energy region $E_\gamma > 40$ MeV becomes practically necessary because of the considerable scatter of the points. In this region a straight line, as is evident from the figure, is sufficiently

is a good approximation and makes it possible to estimate the mean differential cross section for the interval 37–50 MeV (2.18 mb) with a probable error of < 1%. Curve *a* represents the result of differentiating the smooth curve of the integral dependence. For convenience in the representation, the scale of the histogram was reduced by a factor of 2.

As can be seen from Fig. 1, the curve of the cross sections of photonuclear reactions on the Ca^{40} nucleus, along with the giant resonance in the energy region < 22 MeV ($E_{max} = 19.3$ MeV, $\sigma_{max} = 16$ mb, $\Gamma \simeq 3$ MeV), has maxima in the energy regions 22.5–24.0 MeV and 26–28 MeV. The existence of a broad maximum at energies around 33 MeV is not excluded.

Table 1

Integral cross section $\int \sigma\, dE_\gamma$, MeV · mb

Integration interval E_1—E_2, MeV	Literature data	Our data
0—21	43 ([5])	48.0 ± 0.8
0—28	76 ([5])	91.0 ± 1.2
0—23	60 ([6])	62.0 ± 1.0
0—22	53.5 ([7])	55.0 ± 0.8
0—29.5	81 ± 4 ([3])	95.0 ± 1.2
0—33	116 ± 17 ([8])	109 ± 2.0
0—50.5		151 ± 2.2

Note. The error indicated for our data takes into account only the statistical accuracy of the experiment.

Discussion of the results. The region of the giant resonance in the γn-reaction has recently been studied rather thoroughly. In work ([3]), for this purpose, the method of recording the positron activity of the final nuclei Ca^{39}, K^{38}, and Ca^{38} was used; in work ([4]), neutron spectra were studied by the time-of-flight method. In both cases the authors came to the conclusion that a fine structure of the giant resonance was present. Analogous conclusions were also drawn in the study of (γp)- and γp-reactions ([18–20]).

Under our conditions the interval of variation $E_{\gamma\,max}$, $\Delta = 1$ MeV, is too large for detecting the structure of the resonance; however, comparison of its general characteristics ($E_{max}, \sigma_{max}, \Gamma, \int \sigma\, dE_\gamma$) with the results of other investigators

([3,5–8]) leads to quite satisfactory agreement. Table 1 presents, for comparison, data on the integral cross sections.

The maximum observed by us at energies 22.5–24.0 MeV can be compared with the peaks at $E_\gamma = 22.3$ and 24.1 MeV noted in work ([3]), and a rough estimate of the magnitude of the integral cross section corresponding to the energy region in which these maxima are located (the peaks do not stand out very strongly against the general background of the falling cross-section curve) indicates agreement with our data.

Both of the mentioned peaks are located above the threshold of the (γpn)-reaction and, possibly, correspond precisely to this reaction. It is known that the K^{38} nucleus emits positrons with half-lives of 0.95 sec and ~ 7 min, and the ratio of the decay probabilities, according to ([9]), is of order 1. In work ([3]) the 7-minute activity could apparently be recorded only to a small extent, which naturally could have affected the shape of the differential cross section in the indicated energy region.

The study of neutron spectra by the method of thick-layer photoemulsions ([10]) led to the detection of a peak in the neutron-energy region 7.5–9.5 MeV. This corresponds to excitation energies of the Ca^{40} nucleus of 23–25 MeV.

In work ([5]) a weakly expressed maximum was observed at energies around 24.5 MeV. Thus, if all the data are compared, then in the cross section for the energy region 22–25 MeV there exists at least one peak.

A maximum at energies 26–28 MeV in the study of the γn-reaction had not previously been noted. However, certain indications of the existence of a peak in the cross section in the region 26–30 MeV can be obtained from the data of work ([11]) on the study of the γp-reaction. In experiments to determine the total absorption cross section of γ-quanta ([12]), along with the giant resonance, two additional peaks were observed, with maximum energies at 24.7 and 26.1 MeV. But since the absolute values of the cross sections of total absorption and of reactions with emission of

neutrons differ in the energy region 24–28 MeV by approximately a factor of 10, making it difficult to compare the energy positions of the maxima.

Calculations of the parameters of the giant resonance in the dipole absorption of γ radiation by the Ca^{40} nucleus have been carried out in a number of papers (13–16).

A characteristic feature of almost all the calculations is the indication that there exist practically only two intense transitions in the giant-resonance region, at energies 18.4–19.2 MeV (up to 80–90% of the total transition intensity) and 21.4–21.7 MeV (10%). This does not explain the experimentally observed structure of the giant resonance (3, 4). A theory that takes into account only dipole transitions also does not predict the appearance of excited states with energies above 22 MeV, whereas experimentally maxima in the cross section are observed in this energy region.

In this connection it is interesting to note the calculations of cross sections for electric quadrupole transitions carried out in Ref. (17), also on the basis of the shell model with allowance for pair interactions. It turned out that such transitions are concentrated mainly in the energy region 35–40 MeV, with an integral absorption cross section of $\sim$ 30 MeV · mb. The authors suggest that, since the most intense transitions are associated with large values of l, the notions of the quasistationarity of such highly excited levels and the resonance approach to solving the problem are to some extent justified. Judging from our data, although no clearly expressed maxima are observed here, the total increase in the integral cross section reaches 10 MeV · mb. Since the contribution of reactions with proton emission most likely remains appreciable in this energy region as well, agreement with the theoretical estimate may be regarded as satisfactory. This, of course, does not lead to the assertion that quadrupole transitions play the principal role in the excitation of nuclei in the energy region under consideration, but it may serve as an indication of their substantial importance.

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Note: Figure translations are in progress. See original paper for figures.