CROSS SECTION OF THE $Rh^{103}(\gamma, p)$ *REACTION*

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The yield curve of the reaction $Rh^{103}(\gamma, p)$ is measured for energies $E_{\gamma max}$ in the range from 14.5 to 32.5 MeV. The measurements were performed by recording the photoprotons with scintillation spectrometers. The cross section calculated by the Penfold and Leiss matrix method reaches 8 ± 1.5 mb at the maximum (19 ± 0.5 MeV). The half-width at the peak is ~ 5.5 MeV. The cross section increases following a drop in the vicinity of 21—23 MeV, apparently owing to electric quadrupole absorption in the region of 25—30 MeV. The integral cross section for the (γ, p) reaction is 85 ± 15 MeV–mb up to ~ 32 MeV.

RECENT measurements of the cross sections of the (γ, p) reaction on heavy nuclei[1,2], in conjunction with the measurements of angular distributions of photoprotons[3-5], have disclosed the existence in the 25—30 MeV region of maxima of "giant quadrupole resonance." Measurements made on a series of lighter nuclei (Mo[6], Ag[7], $Cd^{112-116}$[8] and Sn^{120}[9]) have shown that the maxima of the cross sections of the (γ, p) reactions on these nuclei are at 20—22 MeV, that is, 4—5 MeV higher than the maxima of the cross sections of the (γ, n) reaction and also of the giant dipole resonances on these nuclei. However, there are no grounds for assuming that the maxima of the (γ, p) cross sections are connected in this case with quadrupole resonances. This is indicated, in particular, by the results of measurements of the angular distributions of photoprotons from Rh and Pr [4,5] irradiated by γ quanta with $E_{\gamma max}$ = 22.5 MeV. Apparently these maxima have a dipole character, and their shift relative to the giant dipole resonance is due to the influence of the Coulomb barrier, which suppresses the low-energy protons and increases by the same token the role of the γ transitions with higher energies. However, measurements of the yields and angular distributions made on Rh and Pr at $E_{\gamma max}$ = 33.5 MeV[4,5] have shown that the cross section is quite large in the region $E_\gamma > 22$ MeV, where rather appreciable quadrupole absorption of quanta occurs. It was therefore considered of interest to measure the cross section of the (γ, p) reaction on one of these nuclei, all the more since Lokan's [7] measurement accuracy was rather low, while Kuo and Ratner[8,9] carried out measurements only up to approximately 27 MeV.

In the present investigation the yield of protons with energy > 3.5 MeV from the $Rh^{103}(\gamma, p)$ reaction was measured by direct registration of the photoprotons with scintillation spectrometers. The arrangement of the apparatus is shown in Fig. 1. The main difficulty in using the scintillation method with a betatron is that the scintillators are highly sensitive to its high electron and γ background level. A considerable part of the background is due to the photoeffect and the Compton effect as well as pair production in the irradiated target. These processes have cross sections $10^2 - 10^4$ times larger than the cross sections of photoproton production, and also a clearly pronounced directivity in the forward hemisphere, so that measurements on sufficiently heavy nuclei are possible only for backward angles. The measurements on Rh were carried out at 90, 120, and 150° to the direction of the γ beam. The scintillators used were thin (~1 mm) crystals of CsI(Tl). The thickness employed was sufficient for the registration

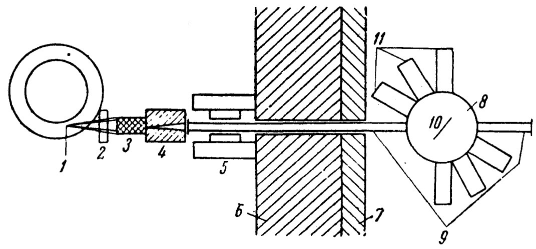

FIG. 1. Arrangement of the apparatus: 1—betatron target, 2—thick-wall chamber—monitor, 3—carbon absorber, 4—collimator, 5—clearing magnet, 6—lead shielding wall, 7—parafin, 8—vacuum chamber, 9—vacuum tubing for the passage of the gamma-ray beam, 10—target of investigated substance, 11—scintillation spectrometers.

of protons with energy ~ 15 MeV, whereas the electrons contributed on the average not more than ~ 0.8 MeV in the crystal. Consequently, background pulses with amplitude equal to the pulse from a proton with energy ~ 3.5 MeV could occur essentially only as the result of superposition of background pulses. To reduce the probability of superposition, the γ-radiation pulse was stretched to about 80 microseconds, and a considerable portion of the low-energy bremsstrahlung spectrum was absorbed in 33.2 g/cm^2 of carbon (the working part of the spectrum with $E_\gamma \gtrsim 15$ MeV was attenuated only approximately 40% in this case).

All these measures appreciably reduced the background, to 10—20% of the total yield. A metallic rhodium 25.1 mg/cm^2 target, situated in a vacuum chamber was used for the measurements, which were carried out in the range from 14.5 to 32.5 MeV in steps of 1 MeV. The measurements of the γ-radiation intensity were carried out with the aid of a thin-wall chamber—a monitor—the readings of which were graduated in terms of the readings of a thick-wall aluminum chamber, similar to that proposed earlier by several authors[10] but the values taken for the sensitivity of the chamber were those given by the recent more precise calculations of Kaminskii[11].

Angular distribution corrections obtained in an earlier investigation[5] were introduced in the yields measured at various angles, and the results were averaged. The values obtained for the yield are shown in Fig. 2. The statistical accuracy of the points is 5—7% in the initial part, but improves to about 1.2% at $E_{\gamma max} > 30$ MeV (sets of approximately 7000 pulses were accumulated). The cross sections of the Rh(γ, p) for different E_γ were calculated by the Penfold and Leiss matrix method[12] from the value of the yield. Account was taken in the calculations for the corrections due to the distortion of the bremsstrahlung spectrum when a stretched γ-ray pulse is used.

The smoothed curve obtained for the energy dependence of the cross section is shown in Fig. 3. The curve has a maximum at $E_\gamma = 19$ MeV. with a half-width ~ 5.5 MeV. The cross section reaches

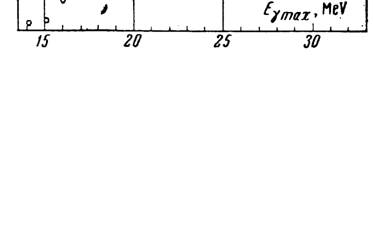

FIG. 2. Plot of measured yield against the energy $E_{\gamma\,max}$.

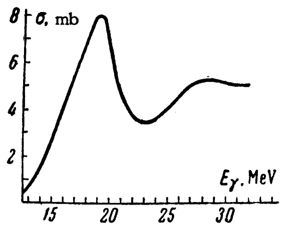

FIG. 3. Plot of the $Rh^{103}(\gamma, p)$ reaction cross section against the energy E_γ.

8.0 ± 1.5 mb at the maximum. It is interesting, in our opinion, that following some decrease the cross section resumes its growth in the 21—23 MeV region and that its variation in the 26—32 MeV region is quite small. From an analysis[5] of the angular distribution of the photoprotons from Rh, we can conclude that the peak at 19 MeV is due to giant dipole resonance in the (γ, p) reaction cross section and that its shift toward higher energies relative to the maxima of the (γ, n) reaction cross section[13-14] is due to the influence of the Coulomb barrier. The same cause apparently explains the much smaller width of the proton cross section peak, compared with the neutron cross section peak, and also the absence of any hint of splitting of the dipole maximum connected with the deformed nature of the Rh^{103} nucleus and manifesting itself clearly in the cross section of the (γ, n) reaction [14]. The region $E_\gamma > 23$ MeV is responsible for the appearance of higher-energy photoprotons, the angular distributions of which have a strong asymmetry relative to 90°[5], indicating an appreciable contribution of E2 absorption in this region.

It is possible that the increase in the cross section for $E_\gamma > 22$ MeV is connected precisely with the absence of a region of quadrupole absorption, which in this case does not have the form of a rather narrow "quadrupole resonance," such as is observed in W and Pb. Of course, the accuracy with which the cross sections are determined in this region is quite low (at the largest values of E_γ the error increases to $\sim 50\%$), and we cannot claim to know the detailed shape of the curve, but the large width of the region where the cross section barely diminishes is not subject to any doubt. This increase in the width of the quadrupole resonance in Rh can be the consequence of the deformed nature of its nucleus, since it can be assumed that when the nucleus is strongly deformed the peak of the quadrupole resonance splits into three peaks, corresponding to quadrupole excitation along the major axes of the ellipsoid (lower peak at $\sim 2h\omega_{\parallel}$), along the minor axis (upper peak at $\sim 2h\omega_{\perp}$), and simultaneous excitation along the major and minor axes (central peak at $\sim h(\omega_{\parallel} + \omega_{\perp})$). In less deformed nuclei this will lead to broadening of the "quadrupole resonance."

The broadening of quadrupole resonance in Rh as compared with W and Pb can occur also as a result of the decrease in the Coulomb barrier and the consequent increase of the nucleon width of the excited states. The determined position of the quadrupole absorption region (25—30 MeV) agrees with calculations by the shell model with account of the residual interactions, recently carried out for several nuclei[15], which show that for the Zr^{90} nucleus, which has a value of A quite close to Rh, the maximum of quadrupole absorption is 5—6 MeV above the zeroth-approximation estimates, that is, at 26—27 MeV. This confirms the appreciable role of residual interactions in quadrupole absorption of γ quanta.

It must be noted that in the energy region above 20 MeV we have determined not the cross section of the (γ, p) reaction, but the total photoproton production cross section, that is, the sum of the (γ, p) and (γ, pn) reaction cross sections (the threshold of the $Rh^{103}(\gamma, pn)$ reaction cross section is 15.7 MeV, but a noticeable yield of this reaction, as in the case of the (γ, p) reaction, can be expected only at γ-quantum energies 4—5 MeV above threshold).

The (γ, pn) reaction is realized essentially upon "evaporation" of a neutron from a sufficiently excited residual nucleus, following the emission of a proton (the probability of a process in which a neutron is emitted before a proton is several orders of magnitude lower). There are presently no data on the cross section of the (γ, pn) reaction on Rh, but by using the spectra of the photoprotons from Rh[5] it would be possible to estimate the upper limit of the contribution of this reaction to the photoproton yield, by assuming that all the protons emitted with energy $E_p < E_{\gamma max} - E_{thr}(\gamma, pn)$ lead to the (γ, pn) reaction. The upper limit of the contribution of the (γ, pn) reaction at $E_{\gamma max} = 22.5$ MeV, obtained in this manner, amounts to 20—25%, increasing to 90% at $E_{\gamma max} = 33.5$ MeV, that is, it is quite high. These facts, however, do not modify the foregoing arguments and deductions concerning the behavior of the photoproton cross section in the region $E_\gamma > 20$ MeV, since these arguments pertain principally to the γ-quantum absorption process.

The integral cross section for photoproton production at energies up to $E_\gamma = 32$ MeV turns out to be 85 ± 15 MeV-mb, with the integral cross section of the dipole peak amounting to 50—55 MeV-mb, that is, 2—3% of the integral cross section of the (γ, n) reaction in the region of the giant dipole resonance, which, in accordance with the latest measurements[14], is 2.13 MeV-b. The integral cross section of the (γ, p) reaction in the region of quadrupole absorption is ~ 30 MeV-mb, that is, 15—20% of the total integral cross section of the quadrupole absorption, determined by the sum rule for E2 transitions[16]. This indicates that, owing to the mixing of the configurations, an appreciable part of the quadrupole transitions leads to the emission of neutrons, which is in agreement with the presence of asymmetry in the angular distributions of the fast photoneutrons, observed for several nuclei[17-19], and confirms additionally the important role of the residual interactions in quadrupole absorption.

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