INELASTIC SCATTERING OF PHOTONS ON Rh^{103} *NUCLEI*

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The yields of the reaction $Rh^{103}(\gamma, \gamma')Rh^{103m}$ were measured by the induced-radioactivity method for various maximum bremsstrahlung energies between 5.9 and 25.5 Mev from a 30-Mev synchrotron. In this energy range the cross section for the reaction $Rh^{103}(\gamma, \gamma')Rh^{103m}$ was calculated from the yield curve by the Penfold and Leiss method. The cross section has two peaks, one at 9.3 Mev near the threshold of the (γ, n) reaction, and the second at ~20 Mev. The peak cross section values are respectively 4.8 and ~ 2.5 mb. The ratio of the radiative and neutron widths is estimated.

THE cross section of inelastic nuclear scattering of γ quanta by rhodium was measured by del Rio y Sierra and Telegdi,[1] who used the method of registering the β activity of Rh^{103m}. The curve for the cross section of the reaction $Rh^{103}(\gamma, \gamma')Rh^{103m}$, obtained by these authors in the energy interval from 8 to 18 Mev, has a sharp peak at 12.8 Mev; the half-width of the peak is 2.9 Mev, and the cross section at the maximum is 12.5 mb. Both the position of the peak and its magnitude contradict other data on inelastic scattering of photons by Y^{87}, Ag^{107}, In^{115}, and Au^{197}, available in the literature.[2-7] For all these nuclei the cross section of the (γ, γ') reaction has a sharp peak near the threshold of the (γ, n) reaction, usually attributed to the competition between the radiative and neutron widths. The height of the peak amounts to ~ 2 — 4 mb. In this connection, we deemed it advisable to make new measurements on rhodium.

Measurements were carried out with the 30-Mev synchrotron of the Physics Institute of the Academy of Sciences. The yields of the $Rh^{103}(\gamma, \gamma')Rh^{103m}$ reaction were measured at different bremsstrahlung energies E_{max} from 5.9 to 25.5 Mev in intervals of ~ 1 Mev. The number of isomer nuclei Rh^{103m} ($T = 56 \pm 1$ min, $E_\gamma = 40 \pm 0.5$ kev) was determined from the induced-radioactivity decay curves.

MEASUREMENT OF THE YIELD CURVE

Samples of high-purity (99.99%) metallic rhodium were in the form of discs 40 mm in diameter. The measurements were carried out with two sample thicknesses: 20 and 50μ (24.8 and 62 mg/cm^2). The samples were irradiated at a distance of 60 cm from the synchrotron target; at the lowest energies the distance was reduced to 40 cm.

The γ-quantum flux incident on the sample during the irradiation time was measured by a thin-wall integrating ionization chamber located in the beam at a distance 50 cm behind the sample. The sensitivity of this chamber was calibrated before and after each irradiation against an "absolute" ionization chamber with thick walls (7.5 cm) of aluminum[8] which replaced the sample in the beam. To obviate a correction for the distribution of the γ-radiation intensity in the beam, the section of the air gap of the "absolute" chamber had the same shape and dimensions as the sample. The gap thickness was 7 mm.

The samples were irradiated from 20 minutes to 2 hours. To introduce corrections for the fluctuation in the intensity of the x rays during the time of irradiation, the voltage of the output of the current integrator of the thin-wall chamber, located in the beam behind the sample, was recorded on the chart of an electronic ÉPP-0.9 potentiometer.

The decay of the Rh^{103m} isomer nuclei is characterized by the following quantities:[9,10]

Transition energy, kev	40
Coefficient of conversion from the K shell, α_K	40
Ratio of conversion coefficients	
on K and L shells	0.09 ± 0.01
on L and M shells	7 ± 1

The yield of the $Rh^{103}(\gamma, \gamma')Rh^{103m}$ reaction was measured with a scintillation counter recording the characteristic x-rays accompanying the conversion from the K shell ($h\nu$ = 22.7 and 20.3

kev). Registration of the gamma radiation made it possible to increase the efficiency by increasing the thickness of the samples, and simplified the corrections for absorption and scattering in the samples. The irradiated sample of rhodium was placed between two NaI(Tl) crystals 40 mm in diameter and 2 mm thick, and consequently the radiation was registered in a solid angle close to 4π. The crystals were hermetically sealed in flat cylindrical boxes. The ends of the boxes, facing the sample, were made of 100-μ aluminum foil. The opposite ends, in contact with the photomultipliers were made of optical glass 1 mm thick. FÉU-29 photomultipliers, connected in parallel had a noise level corresponding to 3—5 kev.

Table I

Reaction	Reaction threshold, Mev	Residual nucleus	Half-life
(γ, γ')	—	Rh^{103m}	56 min
(γ, n)	9.3	Rh^{102}	213 days
$(\gamma, 2n)$	~17.1	Rh^{101m}	4.5 days
$(\gamma, 2n)$	16.8	Rh^{101}	~5 years
$(\gamma, 2p)$	16.5	Tc^{101}	14 min
$(\gamma, 2pn)$	24.8	Tc^{100}	15. sec

In the irradiation of the rhodium by x rays with a maximum energy up to 25.5 Mev, the radioactive isotopes were formed as result of the reactions listed in Table I. The main reactions, the yield of which at these energies amounts to ~90% of the total of all the disintegrations of the rhodium nuclei, are the (γ, n) and $(\gamma, 2n)$ reactions. The yield of the reaction $(\gamma, 2p)$ cannot exceed a fraction of a percent, since the total of the protons from the rhodium due to the reactions (γ, p), (γ, np) and others amounts to not more than 6% of the neutron yield at a maximum energy of 25 Mev.[11] In order to separate most completely the Rh^{103m} decay in the registration of the induced radioactivity of the samples, the amplified pulses from the photomultipliers were fed through a single-channel pulse-height analyzer. This made it possible to reduce considerably the background of the apparatus and the background due to the reactions (γ, n) and $(\gamma, 2n)$. No decay of Tc^{101} was observed under these conditions.

The measurement of the induced activity began 10 or 20 minutes after the end of the irradiation, so as to eliminate the influence of the short-lived isotopes Rh^{104} (T = 44 sec) and Rh^{104m} (T = 4.5 min), which are produced through capture of slow background neutrons [(n, γ) reaction].

A special circuit with electronic "memory," developed by Shtranikh,[12] was used to record the number of pulses every 4 minutes on a telegraph tape. Each decay curve was measured during 2.5 hours. The sensitivity of the apparatus was monitored against a standard source.

In the reduction of the results, corrections were introduced for absorption in the samples (for which purpose the yields from samples of different thickness, simultaneously irradiated, were measured), for the width of the "window" of the pulse-height analyzer, for the solid angle of the apparatus, and for the absorption in the aluminum foil covering the NaI(Tl) crystals.

The irradiation of the rhodium samples in the synchrotron beam could produce, in addition to the (γ, γ') reaction, also metastable Rh^{103m} states due to inelastic scattering of photoneutrons produced in the sample itself and background neutrons around the accelerator. Two control experiments were carried out to estimate these effects:

1) With x rays of maximum energy E_{max} = 25.5 Mev incident on the samples, when the effect due to the background neutrons should be a maximum, one rhodium sample was placed in the beam and the other at the same distance from the synchrotron outside the γ-ray beam. The activity of the latter sample, due to the neutrons and scattered gamma radiation, did not exceed 1% of the activity of the samples placed in the beam.

2) During irradiation at E_{max} = 23 Mev, several rhodium samples were placed between discs of the same diameter, made of cadmium 0.5 mm thick. The yield of the (n, n') reaction due to the neutrons formed in the cadmium should have increased by approximately 20 times. Measurements have shown that the number of Rh^{103m} isomer nu-

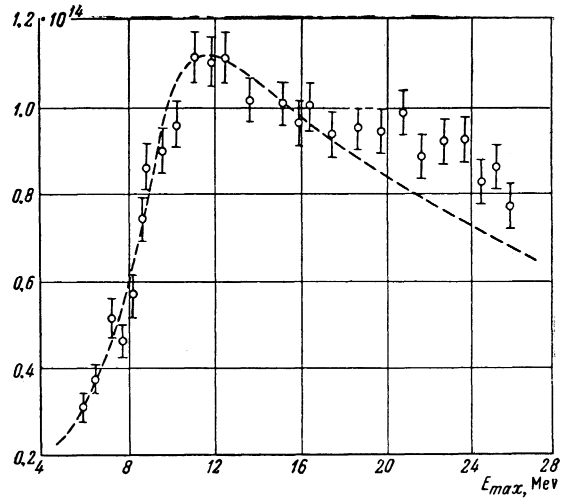

FIG. 1. Yield of the reaction $Rh^{103}(\gamma, \gamma')Rh^{103m}$ at various maximum x-ray energies E_{max}. Ordinates – saturated activity per second per mole per ampere of ionization current of the absolute chamber. The dashed curve is the yield curve calculated under the assumption that the reaction cross section is zero at energies above 12.5 Mev.

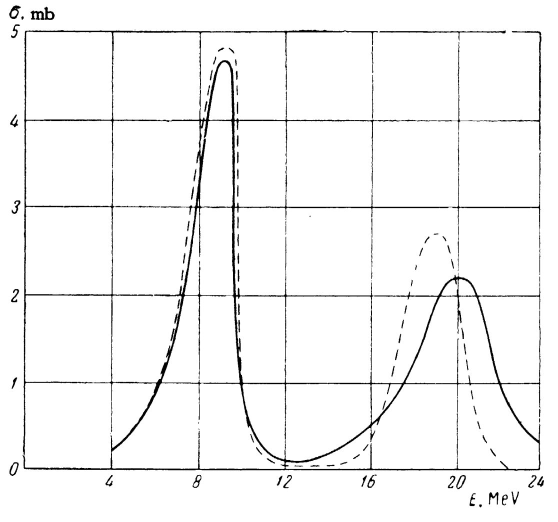

FIG. 2. Cross section of the reaction $Rh^{103}(\gamma,\gamma')\,Rh^{103m}$. Two versions of the calculation are given; other versions yield intermediate values.

clei produced in irradiation with and without cadmium were the same within 5%, i.e., the effect is negligibly small for the sample thicknesses used.

Figure 1 shows the yields of the reaction $Rh^{103}(\gamma, \gamma')Rh^{103m}$ obtained at different maximum bremsstrahlung energies. Each experimental point is the average of 6 — 10 individual measurements (mean-square errors).

INELASTIC SCATTERING CROSS SECTION

The cross section of the reaction $Rh^{103}(\gamma, \gamma')Rh^{103m}$ in the energy interval 5—25 Mev was calculated by the method of Penfold and Leiss[13] from the yields obtained. Figure 2 shows the curves corresponding to the two versions of the calculation.

The cross section has 2 maxima. The position of the first maximum coincides, within the accuracy of the experiment, with the threshold of the (γ, n) reaction. The second maximum is located at ~ 20 Mev, i.e., 3 or 4 Mev above the energy corresponding to the maximum cross section of nuclear photon absorption (16 Mev).[14] The calculated cross section in the vicinity of the first maximum is much less accurate. As a check, Fig. 1 shows dotted the yield curve calculated under the assumption that the cross section of the reaction is zero at energies below 12.5 Mev. A comparison of the dotted curve with the experimental points shows that there is no doubt that the cross section increases in the vicinity of 20 Mev.

The cross section obtained for the $Rh^{103}(\gamma, \gamma')Rh^{103m}$ reaction gives the lower limit for the cross section of inelastic nuclear scattering on rhodium. To obtain from this the total cross section of the (γ, γ') reaction, it is necessary to know the relative probability of production of the isomer state κ in inelastic photon scattering. It is impossible to calculate this quantity with any degree of accuracy, since the branching ratio of the transitions to the ground and metastable states is determined for each excitation energy by all the lower levels of the given nucleus. A rough statistical analysis of the process,[15,16] which agrees qualitatively with the experimental data, yields in the case of rhodium $\kappa = 0.2 - 0.25$.

Knowing the cross section of the (γ, γ') reaction, we can estimate the radiative width Γ_γ for different excitation energies. Table II lists the inelastic scattering cross section $\sigma(\gamma, \gamma') \approx 4.5\sigma[Rh^{103}(\gamma, \gamma')Rh^{103m}]$, and the photoneutron cross section $\sigma_n = \sigma(\gamma, n) + \sigma(\gamma, 2n)$, measured by Parsons.[14] Starting with the threshold of the (γ, n) reaction, the neutron width Γ_n increases rapidly, and the cross section of the reaction (γ, γ') accordingly diminishes rapidly. In the energy interval 9.35 — 11 Mev the ratio of the cross sections $\sigma(\gamma, \gamma')/\sigma_n$, the value of which is 2 at 9.35 Mev, decreases to 0.09 at 10 Mev, and to 0.03 at 11 Mev. Up to 16 Mev, the ratio of the cross sections $\sigma(\gamma, \gamma')/\sigma_n$ remains approximately constant at ~ 0.01. Starting at 16 or 17 Mev, the relative probability of inelastic scattering increases and amounts to ~10% at 20 Mev.

Table II

E, Mev	$\sigma(\gamma, \gamma')$, mb	σ_n, mb	$\sigma(\gamma, \gamma')/\sigma_n$	E, Mev	$\sigma(\gamma, \gamma')$, mb	σ_n, mb	$\sigma(\gamma, \gamma')/\sigma_n$
5	1.8	—	—	12	0.6	62.1	0.01
7	8.5	—	—	14	1.2	155.2	~0.01
9.3	21.2	—	—	16	2.7	193.1	~0.01
9.35	21.1	10.3	2.04	18	6.1	169.0	0.04
9.5	14.8	17.2	0.86	19	9.2	136.2	0.07
9.75	4.4	25.2	0.18	20	10.3	111.0	0.09
10	2.6	27.6	0.09	21	8.7	87.9	0.10
11	1.0	37.2	0.03	22	4.4	71.7	0.06

If the nuclear excitation energy is several Mev higher than the threshold energy of the (γ, n) reaction, the emission of a photon can with a large probability be accompanied by an emission of a neutron [reaction $(\gamma, \gamma n)$]. In this case the ratio $\sigma(\gamma, \gamma')/\sigma_n < \Gamma_\gamma/\Gamma_n$. According to an estimate made by Goldemberg and Katz,[4] $\Gamma_\gamma/\Gamma_n \approx 3\sigma(\gamma, \gamma')/\sigma_n$ near 20 Mev. This means that in the case of rhodium the radiative width at 20 — 22 Mev amounts to 25 — 30% of the neutron width. The strong increase in the radiative width in the 20-Mev region, obtained for rhodium, confirms the results obtained earlier[3,6] for Ag^{107} and In^{115}.

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