[1] D. R. Bates et *al.*, Phil. Trans. Soc. (London) **A243**, 93 (1950).

[2] P. M. Morse and W. P. Allis, Phys. Rev. **44**, 269 (1933).

[3] G. A. Erskine and H.S.W. Massey, Proc. Roy. Soc. (London) **A212**, 521 (1952).

[4] H.S.W. Massey and B. L. Moiseiwitsch, Proc. Roy. Soc. (London) **A227**, 38 (1954).

[5] G. F. Drukarev, J. Exptl. Theoret. Phys. (U.S.S.R.) **25**, 139 (1953).

[6] V. A. Fock, J. Exptl. Theoret. Phys. (U.S.S.R.) **10**, 961 (1940).

[7] M. J. Seaton, Phil. Trans. Roy. Soc. (London) **A245**, 469 (1953).

[8] L. D. Landau and E. M. Lifshitz, *Quantum mechanics*, Moscow-Leningrad, 1948, Ch. IX, Sec. 61.

Translated by R. T. Beyer
51

SOVIET PHYSICS JETP VOLUME 4, NUMBER 3 APRIL, 1957

Inelastic Scattering of Photons by Indium-115 Nuclei

O. V. BOGDANKEVICH, L. E. LAZAREVA AND F. A. NIKOLAEV
P. N. Lebedev Physical Institute, Academy of Sciences, USSR
(Submitted to JETP editor April 4, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 405-412 (September, 1956)

The yields of the reactions $In^{115}(\gamma, \gamma')In^{115m}$ and $In^{115}(\gamma, 2n)In^{113m}$ and the yield of neutrons accompanying the photodisintegration of indium were measured at various maximum energies of x-rays from 5 to 27 mev. Cross sections were calculated by the photon difference method.

THE yield of the reaction $In^{115}(\gamma, \gamma')In^{115m}$ at various maximum x-ray energies E_{max} from 5 to 27 mev was measured on the 30 mev synchrotron. The number of isomeric states of In^{115m}, formed after the irradiation, was measured by a scintillation counter which registers the γ-radiation emitted during the transition from the metastable level to the ground level ($h\nu = 335$ kev, $T = 4.5$ hours).

If the conversion coefficient is not very large, this method of registration of metastable states seems to be more effective than the measurement of the induced activity by means of soft conversion electrons, since it makes possible a considerable increase in the number of counts at the expense of increasing the effective thickness of the sample, and simplifies the corrections for absorption and scattering of the radiation which is being registered. The photo-excitation cross sections of the metastable state of In^{115m} so obtained give a lower bound for the cross section of the reaction $In^{115}(\gamma, \gamma')$.

In reducing the γ-decay curves of the activity induced in the indium sample, the yield curve of the reaction $In^{115}(\gamma, 2n)In^{113m}$ was also obtained.

For simultaneous comparison of radiative and neutron width at various energies of x-rays, neutron fields during photodisintegration of indium were measured.

1. YIELD CURVE OF THE REACTION $In^{115}(\gamma,\gamma')In^{115m}$

The sample of indium (95.8% In^{115}; 4.2% In^{113}), 2.55 gm/cm^2 thick, was irradiated at a distance of 60 cm from the target of the synchrotron. In order to decrease the γ-activity arising as a result of capture of slow neutrons [$In^{115}(n, \gamma)In^{116m}$, $T = 54$ min], the sample of indium was placed during irradiation in a cadmium case (wall thickness 0.5 mm) wrapped in rhodium foil 0.4 mm thick.

The flux of γ-quanta falling on the sample was measured with an ionization chamber with thick aluminum walls (7.5 cm). The ionization in the air spaces of such a chamber for bremsstrahlung was calculated in Ref. 1. The measurement of the x-ray flux was made by placing the chamber at the position of the sample each time before and after irradiation. In order to avoid having to make a correction for the distribution of the γ-quanta flux over the surface of the sample, the cross section of the air space in the aluminum block had the shape and dimensions of the irradiated surface of the sample (40×40 mm).

After irradiation, the duration of which at different energies varied from 20 min to 4 hrs, the disintegration curve of the γ-decay induced in the sample was taken over a period of 12/24 hrs.

The γ-activity was measured with the aid of a set-up consisting of two multipliers (FEU-19) working on coincidences from the same NaI crystal. The NaI crystal (diameter 32 mm, thickness 20 mm) was located in a cylindrical box filled with vaseline jelly. The bottom and top of the box, which were in contact with the photocathodes of the multipliers, were of quartz glass 1 mm thick, the side walls of aluminum 1 mm thick. Indium samples in the form of two strips 19 mm wide were wrapped around the lateral surface of the box with the crystal.

The photomultipliers were operated at 900 volts. Before arriving at the coincidence scheme, the impulses from the multipliers were amplified by a saturated amplifier with amplification factor of 4×10^4. The low supply voltage of the multipliers completely eliminated the optical coupling observed at high voltages and markedly lowered the number of noise impulses, which made it possible to use the Rossi type coincidence scheme $\tau = 10^{-6}$ sec with good selection coefficient. High amplification and amplitude form of the impulses guaranteed a high effectiveness and stability of functioning of the apparatus.

The effectiveness of the apparatus in registering the γ-rays of 335 kev, emitted in the transition of In^{115} from the isomeric state to the ground state, was measured with the aid of a standard source Cr^{51} ($h\nu = 330$ kev), prepared in the Isotope Laboratory of the Academy of Sciences. Cr^{51}, in the form of chromium sulfate, was deposited in a thin layer on a strip of aluminum foil 19 mm wide. The activity of the source was determined with accuracy of ±5%. in measuring the effectiveness of the apparatus the foil with the radioactive layer deposited on it was wrapped around the NaI crystal instead of the indium sample. In order to make a correction for absorption of γ-rays in the indium sample (1.20 ± 0.2), the absorption curve in indium of γ-rays from Cr^{51} source was determined with the same geometry.

In the decay of In^{115m} 94.5% of the nuclei pass into the ground state of In^{115} and 5.5% undergo β-decay ($E_{max} = 0.84$ mev). Electrons were not registered by the apparatus since they were practically totally absorbed in the walls of the box containing the NaI crystal.

The coefficient of internal conversion of γ-rays emitted in the isomeric transition of In^{115m} was measured in Refs. 2-5. Experimental values obtained in these papers coincide to within 15%; the mean value of the conversion coefficient $\alpha = 0.98$.

Figure 1*a* gives the yield curve obtained for the reaction $In^{115}(\gamma, \gamma')In^{115m}$ after introducing the correction for internal conversion and 5.5% β-transitions. The x axis gives maximum energy of x-rays, E_{max}, the y axis, the number of isomeric nuclei In^{115m} formed per second during irradiation of a mol of In^{115} by a flux of x-rays which produces in the air space of the thick-walled aluminum chamber a current of 1 A. Each point represents an average of 4 to 6 separate measurements. Mean square errors are also given.

The absolute yield of the reaction $In^{115}(\gamma,\gamma')^{115m}$ at maximum energy $E_{max} = 15.75$ mev, as a control, was measured using electrons of internal conversion. For this, indium samples with diameter of 40 mm and thickness 100-250 mg/cm^2 were irradiated in the cadmium case, wrapped in rhodium foil, and the curves of β-decay were measured with a column counter (window diameter 40 mm; thickness of mica covering the window, 4.5 mg/cm^2). The value of yield obtained is given in Fig. 1*a*. The absolute yields obtained by the two different methods agree to within 14%. The ratio of yields at $E_{max} = 16.7$ and 26.5 mev, measured by means of conversion electrons, also agrees, within experimental error, with the ratio obtained by the method of registering γ-radiation.

Metastable states of In^{115m} could be partially excited as a result of inelastic scattering of background neutrons and photoneutrons formed in the sample [$In^{115}(n, n')In^{115m}$]. Since the neutron background around the synchrotron is approximately isotropic, in order to estimate the effect caused by background neutrons, at energies $E_{max} = 16.7$ and 26.5 mev, controlled irradiations of indium samples were made outside of the x-ray beam. In these indium samples, while activity with period $T = 54$ min was present, no noticeable activity with period of half-life of 4.5 hours was observed. From the ratio of number of background neutrons to the number of photoneutrons formed in the sample, as measured in the present investigation (see Sec. 2), it follows that the fraction of isomeric states of In^{115m} connected with the inelastic scattering of neutrons, did not exceed 2-3%.

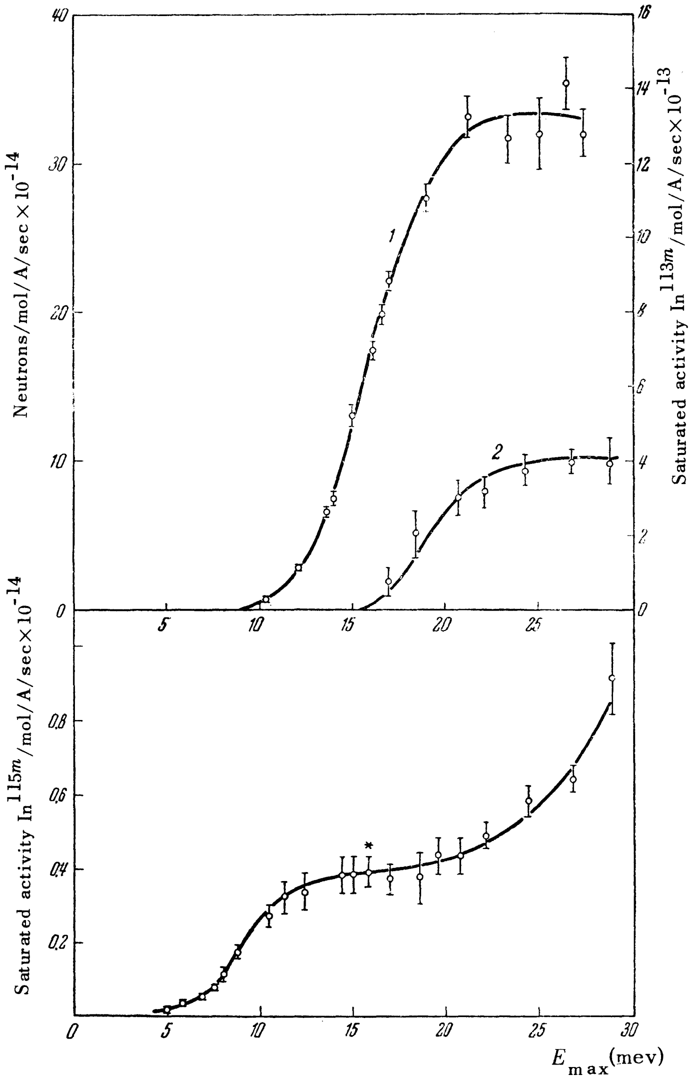

FIG. 1. a – yield curve of reaction $In^{115}(\gamma,\gamma')In^{115m}$. Star indicates yield of reaction measured by menas of internal conversion electrons; b: 1 – photoneutron yield curve; 2 – yield curve of reaction $In^{115}(\gamma, 2n)In^{113m}$ (scale on the right).

2. PHOTONEUTRON YIELD CURVE

In measuring the neutron yield, the indium sample was placed at the center of a paraffin block (80 × 80 × 70 cm) in a transparent canal of 5 cm diameter, along the axis of the x-ray beam. Neutrons, emitted in the photodisintegration of indium, after slowing down in the paraffin, were registered by a KH-14 ionization chamber filled with BF_3. The indium sample was a disc of 4 cm diameter and 4.97 gm/cm^2 thick.

In order to maintain the same conditions of neutron absorption in measuring the neutron yield from the sample and in measuring the background, the sample was placed in an aluminum box with double walls between which boron carbide powder was poured (0.5 gm/cm^2). In measuring the background, instead of the sample, an empty box with boron carbide was placed in the paraffin block. At various maximum enegies of x-rays the background was from 10 to 40%.

The absolute yield of neutrons was determined from the ratio of neutrons registered with the irradiated sample to the neutrons from the standard source (Ra_α + Be) placed, instead of the sample, in the box with boron walls. The intensity of the source was measured with accuracy of ±6%. During the standardization process, curves were taken of the space distribution of neutrons for the sample and for the standard source.

In order to introduce a correction for absorption of x-rays in the indium sample, curves were taken of the dependence of neutron yield on thickness of the irradiated sample, for three different energies E_{max}. The method of neutron registration is described in detail in Refs. 6 and 7.

The flux of γ-quanta was measured with an ionization chamber with thick aluminum walls, as in the measurements of yield of the reaction $In^{115}(\gamma, \gamma')In^{115m}$ (Sec. 1). The irradiated surface of the sample and the cross section of the air space of the chamber were the same.

Figure 1*b* gives the yield curve for photoneutrons from indium, measured from the threshold of the reaction (γ, n) to E_{max} = 27 mev (curve *1*). Since the indium sample contains 95.8% of the isotope Indium-115, and for nuclei with $Z \sim 50$ neutron yields for photodisintegration of different isotopes of the same element differ little[8-10], the curve in question is practically the one for In^{115}.

The same figure gives the yield curve for the reaction $In^{115}(\gamma, 2n)In^{113m}$ (curve *2*). The yield of this reaction was obtained from the decay curve of induced γ-activity in the measurement of the yield of the reaction $In^{115}(\gamma, \gamma')In^{115m}$ (Sec. 1).

The metastable state In^{113m} ($h\nu$ = 392 kev, T = 105 min) is also excited during the reaction $In^{113}(\gamma, \gamma')In^{113m}$. Because of the relatively small proportion of the isotope In^{113}, the formation of In^{113m} must be attributed to the process (γ,2n). The yields of the reaction $In^{115}(\gamma, 2n)In^{113m}$ were measured with low accuracy, since the separation of the γ-activity of In^{113m} (with half-life T = 105 min) after separating out the activity of In^{115m} (against the background of a marked activity with period of T = 54 min resulting from the reaction $In^{115}(n, \gamma)In^{116m}$) involves large errors, especially near the threshold of the reaction (γ, 2n) – $E_{n,n}$ = 15.5 mev.

The effectiveness of the apparatus and the correction for absorption in the indium sample for the γ-rays of In^{113m} were obtained by recomputing the corresponding quantities determined for the γ-rays of the standard source Cr^{51}. The coefficient of internal conversion α = 0.39 ± 0.04 was taken from Ref. 4.

3. CROSS SECTION CURVES

From the yield curves given in Fig. 1, differential cross sections were computed. For the bremsstrahlung spectrum, the Schiff spectrum was used, corrected for absorption of γ-rays in the walls of the accelerator chamber. The calculation was made by the method of photon difference over the interval of 1 mev.

Figrue 2 gives the cross-section curve obtained for the reaction $In^{115}(\gamma, \gamma')In^{115m}$.

Curves for cross section for photoexcitation of the metastable state In^{115m} were also obtained in the paper of Goldemberg and Katz[11] (up to 18 mev) and by Burkhardt, Winhold and Dupree[12] (up to 14 mev). In these investigations the reaction yield was measured by means of the conversion electrons.

Table I gives the basic characteristics of the cross-section curve of the reaction $In^{115}(\gamma,\gamma')In^{115m}$ obtained in the present paper and in Refs. 11 and 12. The maximum of the cross section, within limits of error, coincides with the maximum cross section obtained in Ref. 11. The shape of the curve, given in Fig. 2, agrees rather well, in the region of the maximum, with the value obtained in Ref. 12.

The sharp drop in the cross section at the threshold of the reaction (γ, n) – (9.05 ± 0.2) mev is connected with the exponential increase in neutron width. Completely unexpected was the sharp increase of the cross section starting at the energy ~ 16 mev.

The samples of indium used in this investigation were of high purity ($\geq$ 99.5%), and possible impurities could not produce the sharp increase in yield observed at energies $E_{max} > 20$ mev.

In the photodisintegration of indium, of all reactions energetically possible at these energies, a decay period near to the period T = 4.5 hours, is produced only with the reaction $In^{115}(\gamma, 2p)Ag^{113}$ (binding energy $E_{p,p}$ = 17.3 mev). The silver isotope 113 decays with period T = 5.3 hours; the limiting energy of the β-spectrum E_{max} = 2.1 mev; no γ-radiation accompanying the decay was observed. In order to check whether the rise in the yield curve is not due to the reaction (γ, 2p),

β-activity of the samples irradiated at energies $E_{max} = 16.7$ and 26.5 mev was measured with a column β-counter without a filter and with an aluminum filter 130 mg/cm^2 thick which absorbs electrons of energy below 400 kev. At both energies (16.7 mev and 26.5 mev), the aluminum filter completely absorbed the β-activity attributed to the decay of In^{115m}.

The increase of the observed γ-activity could be due to the formation of a heretofore unknown isomer with a not too different decay period. In order to exclude this possibility, the spectrum of γ-radiation from indium samples irradiated with x-rays with $E_{max} = 16.1$ and 25.1 mev was measured with a scintillation spectrometer. In both cases a sharp peak was observed at the energy 335 kev, whose amplitude decreased by one-half in 4.5 hrs. In the case $E_{max} = 25.1$ mev, the amplitude of the peak was ~ 1.9 times greater than with $E_{max} = 16.1$ mev.

Control experiments were made which showed that the increase of the yield of the reaction at energies $E_{max} > 20$ mev, observed both with γ-ray and with conversion electron registration, is obviously due to the increase in the cross section for photo-excitation of In^{115m}.

The emission of photons by excited nuclei of In^{115} does not lead to the isomeric state In^{115m} in all cases. If the ratio of transitions to the ground and the metastable states is known, it is possible to obtain the cross section for the reaction $In^{115}(\gamma, \gamma')$.

The analysis of the ratios of the cross sections of (γ, n) reactions leading to the ground and the isomeric states, carried out in the paper of Katz, Becker and Montalbetti[11,13], shows that these ratios are practically unchanged when the excitation energy varies from 10 to 20 mev, and that transitions between levels with not too different values of spin are more probable than transitions between levels with large spin differences. The spins of the ground and the metastable levels of indium-115 nuclei are, respectively, 9/2 and 1/2. With dipole absorption of γ-quanta the spins of the excited nuclei may be 11/2 (0.400); 9/2 (0.336) and 7/2 (0.267); the numbers in parentheses give the statistical weight of the state with the spin in question. Transitions to the ground state must be much more probable than the transitions to the metastable state.

In each individual case the transition probability must depend on the properties of low-lying levels[13]. A rough statistical consideration shows that the ratio of the number of states passing in cascade into the ground state through a metastable state, to the total number of transitions to the ground state, is $(2I_m + 1)/(2I_m + 1) + (2I_g + 1)]$, where I_m and I_g are the spins of the metastable and the ground state[14]. In the case of In^{115m} this ratio is 1/6.

A coefficient equal to 6 is also obtained from the following estimate. Near the threshold of the reaction (γ, n), the competing reactions are (γ, n) and (γ, γ'). Below the threshold of the reaction (γ, n) the cross section for absorption of γ-quanta is $\sigma_\gamma = \sigma(\gamma, \gamma')$, while above the binding energy of the neutron, $\sigma_\gamma = \sigma(\gamma, \gamma') + \sigma(\gamma, n)$, and even at energies 11 to 12 mev $\sigma_\gamma \approx \sigma(\gamma, n)$. Since the cross section for absorption of γ-quanta must change continouusly with energy, it is possible to obtain an estimate of the upper bound of the (γ, γ') cross section by extrapolating the curve for $\sigma(\gamma, n)$ from 11-12 mev into the region below 9 mev.

Figure 3 gives the curve, obtained in this investigation, of the photoneutron cross section $\sigma_n = \sigma(\gamma, n) + 2\sigma(\gamma, 2n) + \sigma(\gamma, pn)$. The extrapolated value of the cross section σ_γ at energy of 8.6 mev, equal to 10.5-12 mbn, is six times greater than the cross section for the reaction $In^{115}(\gamma, \gamma')In^{115m}$, obtained in this investigation. Thus the cross section for the reaction $In^{115}(\gamma,\gamma')$ equals the measured cross section of the process $In^{115}(\gamma, \gamma')In^{115m}$ multiplied by the coefficient 6.

Comparison of the cross section of the reaction (γ, γ') with the photoneutron cross section σ_n makes it possible to compare the radiative and neutron width at various energies of excitation of In^{115} nuclei.

The yield curve for photoneutrons from indium was also obtained by a method similar to the one described in Sec. 2.up to energy $E_{max} = 24$ mev by Montalbetti, Katz and Goldemberg[8]. The curve for σ_n obtained by these authors is given in Fig. 3 (dotted line). Table II gives the main characteristics of the cross section σ_n, obtained in this investigation and in Ref. 8. Integral cross sections and maximum cross sections, obtained in both investigations, agree to within 15%. The 1.5

times greater value of the cross section of the reaction $In^{115}(\gamma, n)$ obtained in Ref. 11 by the induced β-activity method, is apparently due to the large errors incurred in separating out the long-lived activity of In^{114m} ($T = 49$ days).

The ratio of the cross sections $\sigma(\gamma,\gamma')/\sigma_n$, equal to ~1 at energy 9.5 mev, at first sharply decreases with increase of energy. At 11 mev it equals ~ 1/10. In the region of the dipole maximum, the cross section for the reaction (γ, γ') is about 2% of the cross section for the reaction (γ, n).

TABLE I. Photoexcitation cross section of the Isomeric state of In^{115m}.

Authors	Position of maximum of cross section, mev	Cross section at max, mbn	Half-width of peak, mev	Integral cross section to 18 mev mev-bn
Goldemberg, Katz	9	2.2*	9	0.0167*
Burkhardt, Winhold, Dupree	8 ± 1	1.18 ∓ 0.35	2 ∓ 1	—
Bogdankevich, Lazareva, Nikolaev	$8.6\mp0,5$	1.92 ∓ 0.29	2.6	0.0112 ∓ 0.017

* Cross sections were recomputed for conversion coefficient $\alpha = 0.98$ instead of $\alpha = 0.33$, used in Ref. 11.

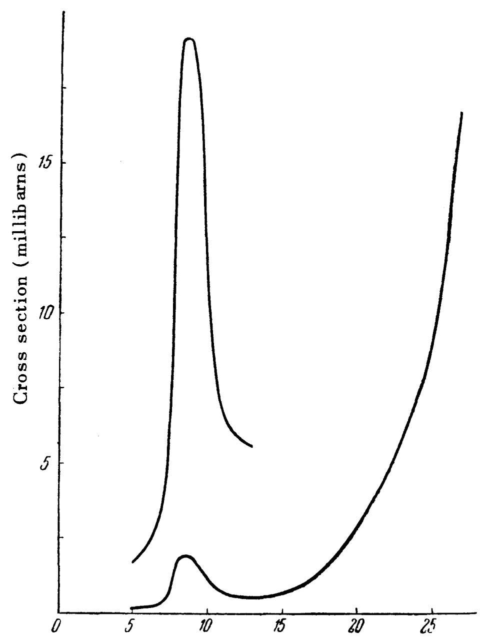

FIG. 2. Cross section of the reaction $In^{115}(\gamma,\gamma')In^{115m}$. The upper curve is on a ten-fold scale.

Since on the average the photon carries off an energy much smaller than the total energy of excitation of the nuclei, the emission of a photon has a large probability of being accompanied by the emission of a neutron [reaction $(\gamma, \gamma' n)$]. This decreases the cross section $\sigma(\gamma, \gamma')$ and increases the cross section of the reaction (γ, n). According to estimates made in Ref. 11, at energies 14-15 mev the ratio of the cross sections $\sigma(\gamma,\gamma')/\sigma(\gamma,n)$

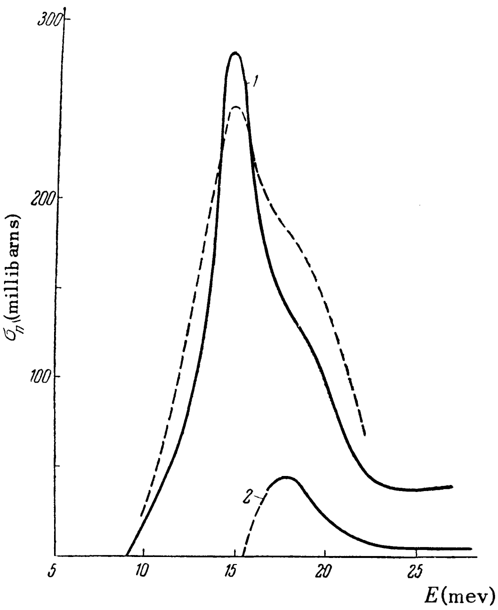

FIG. 3. 1 – cross section $\sigma_n = \sigma(\gamma, n) + 2\sigma(\gamma, 2n) + \sigma(\gamma, pn)$ calculated for the yield curve for neutrons accompanying the photodisintegration of indium; dotted line gives $\sigma_n(E)$ obtained in Ref. 8; 2 – cross section of reaction $In^{115}(\gamma, 2n)In^{113m}$, times coefficient 6.

is 1.5 to 2 times less than the ratio of the corresponding widths Γ_γ/Γ_n. Therefore, at energies about 15 mev the radiative width is 3 to 4% of the neutron width. Starting at the energy ~16 mev, the cross section for the reaction $In^{115}(\gamma,\gamma')$ increases sharply, reaching, at 27 mev, a value ~100 mbn. To some extent the increase in the cross section for the reaction $In^{115}(\gamma, \gamma') In^{115m}$ may be due to increase in probability of transition of excited nuclei to the metastable level. In this case the cross section of the reaction $((\gamma, \gamma')$ would be less. However, the observed increase in the cross section for photoexcitation of the metastable state In^{115m} cannot be explained without assuming a strong increase in radiative width.

TABLE II. Principal characteristics of the photoneutron cross section σ_n.

Authors	Position of maximum of cross section, mev	Cross section at maximum, mbn	Half width of curve, mev	Integral cross section mev-bn
Montalbetti, Katz, Goldemberg	15.2	250	8.0	~2,0 (up to 22 mev)
Bogdankevich, Lazareva, Nikolaev	15.1∓0.5	280∓29	~5.0	1.8∓0.2 (up to 27 mev)

The marked increase in probability of radiation at energies above 20 mev is supported by a comparison of the photoneutron cross section σ_n and the cross section for the reaction $In^{115m}(\gamma,2n)In^{113m}$.

As in the case of the reaction (γ, γ'), upon emission of two neutrons, the 113 isotope of indium is formed in the ground and the isomeric states. In the ground state In^{113} has spin 9/2, in the isomeric state, 1/2. According to a statistical estimate, the probability of decay of the excited nucleus through a metastable state is also 1/6. Figure 3 gives the curve of the cross section $\sigma(\gamma, 2n) = 6 \cdot \sigma[In^{115}(\gamma, 2n) In^{113m}]$, (curve 2).

Knowing the cross section of the reaction $(\gamma, 2n)$, from the curve $\sigma_n = \sigma(\gamma, n) + 2\sigma(\gamma,2n) + \sigma(\gamma, pn)$ it is possible to find the ratio $\sigma(\gamma, 2n)/[\sigma(\gamma, n) + \sigma(\gamma, pn)]$. The proton-neutron binding energy $E_{n,p}$ = 16 mev, the height of the Coulomb barrier is ~10 mev. The yield of photoprotons from indium at E_{max} = 24 mev forms only 1.2% of the photo-neutron yield[15]. At excitation energy E = 17.5 mev the ratio $\sigma(\gamma, p)/\sigma(\gamma, n)$ for indium does not exceed 1-2%[16]. Hence, up to energy ~23 mev the cross section of the reaction (γ, pn) must be relatively small and the ratio

$$\sigma(\gamma, 2n)/[\sigma_n - 2\sigma(\gamma, 2n)] \approx \sigma(\gamma, 2n)/\sigma(\gamma, n).$$

The ratio $\sigma(\gamma, 2n)/\sigma(\gamma, n)$ calculated from the data given in Fig. 3, at first increases to 0.9 at energy of 18 mev, in agreement with estimates made according to the statistical theory. Instead of further increase of the relative probability of the reaction $(\gamma, 2n)$ the ratio $\sigma(\gamma, 2n)/\sigma(\gamma, n)$ decreases to ~0.2 at 23 mev. If the cross section for nonelastic scattering of photons on In^{113} nuclei increases as in the case of In^{115}, then, at energies higher than 20 mev, Un^{113m} is formed in a fraction of the cases due to photoexcitation of the isomeric state of indium 113 and the cross section of the reaction $(\gamma, 2n)$ is still smaller.

The decrease of the relative probability of the reaction $(\gamma, 2n)$ with increase of nuclear excitation energy can take place only when there is a decay process competing with neutron emission, whose probability increases sharply from 18 to 23 mev. This is in agreement with the observed sharp increase of photon emission probability at energies of 16-27 mev.

In conclusion, the authors express their gratitude to Prof. V. I. Veksler for discussion of the results.

[1] Flowers, Lawson and Fossey, Proc. Phys. Soc. (London) **65B**, 286 (1952).

[2] Langer, Moffat and Graves, Phys. Rev. **86**, 632 (1952).

[3] J. L. Lawson and J. M. Cork, Phys. Rev. **57**, 982 (1940).

[4] I. V. Estulin and E. M. Moiseeva, J. Exptl. Theoret. Phys. (U.S.S.R.) **28**, 541 (1955); Soviet Phys. JETP **1**, 463 (1955).

[5] Jagdish Varma and C. E. Mandeville, Phys. Rev. **97**, 977 (1955).

[6] Valuev, Gavrilov, Zatsepina and Lazareva, J. Exptl. Theoret. Phys. (U.S.S.R.) **29**, 280 (1955) Soviet Phys. JETP **2**, 106 (1956).

[7] Lazareva, Ratner and Shtranikh, J. Exptl. Theoret. Phys. (U.S.S.R.) **29**, 274 (1955); Soviet Phys. JETP **2**, 301 (1956).

[8] Montalbetti, Katz and Goldemberg, Phys. Rev. **91**, 659 (1953).

[9] R. Nathans and J. Halpern, Phys. Rev. **93**, 437 (1954).

[10] B. I. Gavrilov and L. E. Lazareva, J. Exptl. Theoret. Phys. (U.S.S.R.) **30**, 855 (1956); Soviet Phys. JETP **3**, 871 (1956).

[11] J. Goldemberg and L. Katz, Phys. Rev. **90**, 308 (1953).

[12] Burkhardt, Winhold and Dupree, Phys. Rev. **100**, 199 (1955).

[13] Katz, Baker and Montalbetti, Canad. J. Phys. **31**, 250 (1953).

[14] Martin, Diven and Taschek, Phys. Rev. **93**, 199 (1954).

[15] M. E. Thoms and W. E. Stephens, Phys. Rev. **92**, 362 (1953).

[16] O. Hirzel and H. Waffler, Helv. Phys. Acta **20**, 373 (1947).

Translated by A. V. Bushkovitch
82