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Integrated cross sections for excitation of nuclear isomers by inelastic photon scattering at giant resonance

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HIGHLIGHTS

- Photoexcitation of nuclear isomers prevails in the energy region below neutron emission threshold.
- It almost vanishes at giant resonance, hence excitation cross sections go to saturation beyond threshold.
- Experimental and calculated integrated cross sections are given for 26 isomers.

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ABSTRACT

In the view of the evidences arising from our experimental and theoretical studies, the long-standing picture of a two-humped excitation function for photoexcitation of isomers cannot be confirmed. Whereas the first maximum (at the photoneutron threshold) of the cross section of nuclear photon scattering can be attributed to inelastic (compound) scattering, the second large peak at about giant dipole resonance is mostly due to the elastic (direct) process. A second large peak or increase reported to appear in isomer production has been shown to be practically vanishing. On realizing such a situation, calculated estimates have been given for saturated integral cross section values for isomer activation, based on photoabsorption cross sections taken from the usual Lorentzian parametrization up to the photoneutron threshold. Results compare reasonably well to available experimental data acquired by gamma-ray spectrometry in a large set of stable nuclides having long-lived isomeric states.

Nuclear photon scattering has long been considered to have a double-humped excitation function showing a maximum at the neutron binding energy, where it drops sharply, then attains a maximum again (Bethe and Ashkin, 1953) at about giant resonance (GR), though its amplitude represents a few per cent only of the total absorption. This picture, however, leaving elastic and inelastic scattering unspecified, was usually related to both processes in the literature. On the basis of early reports exhibiting doubly-peaked cross sections both in elastic photon scattering (Fuller and Hayward, 1956) and isomer excitation (Meyer-Schützmeister and Telegdi, 1956; Silva and Goldemberg, 1958; Bogdankevich et al., 1960, 1963), the foregoing belief became widespread, in spite of an obvious anomaly (Bogdankevich et al., 1956; Levinger, 1960). Whereas it is difficult to fully separate elastically and inelastically scattered photons from each other, nuclear isomers can evidently be photoexcited via inelastic scattering only. However, isomers are also produced via neutron induced reactions, which have much higher cross sections, and presence of neutrons is unavoidable in the GR region.

In contrast with both early and more recent (Mazur et al., 1993) (Demekhina et al., 2001) experimental results, our ^{99}Tc, ^{103}Rh, ^{115}In isomer excitation experiments, supported also by model calculations, do not confirm the existence of a comparable size second peak or increase in the cross section (Sekine et al., 1991; Sáfár et al., 1991; Lakosi et al., 1992, 1993/1, 1993/2). A subsequent study provided similar result for ^{93}Nb as well (Sáfár and Lakosi, 1993). More recent calculations for ^{77}Se, ^{83}Kr, ^{89}Y, ^{107}Ag, ^{111}Cd, ^{113}In, ^{123,125}Te, ^{167}Er, ^{179}Hf, ^{180}Hf, and ^{193}Ir further confirm this feature. Even if there is a minute calculated second peak in the giant dipole resonance (GDR) region, it remains order of magnitudes smaller than the first one at the (γ,n) threshold or the second one reported in the literature, and can hardly be observed within the accuracy of our measurements. Thus, this feature seems to be general. In other words, beyond particle threshold there is virtually no isomer production by (γ,γ′) reaction. It is of note that no considerable increase appears at GDR in $(n,n')^m$ reaction cross sections, either.

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Our experiments were carried out by bremsstrahlung produced on a Pt converter by 14–50 MeV electrons from the ELINAC at the Laboratory of Nuclear Science, Tohoku University, Sendai, Japan (Sekine et al., 1991; Sáfár et al., 1991). The integrated cross sections at the individual energies were evaluated from the isomer activities measured by a Ge detector and determining gamma fluxes. The latter was calculated according to Schiff's formula (Schiff, 1951), and the amplitude was fitted to measured activities of flux monitors. The photoneutron flux density was estimated using the cascade evaporation model (Sáfár and Lakosi, 1994). The contribution of photoneutron activation proved to be of the order of per cent only.

Calculations (Sáfár et al., 1991) were performed in the framework of a spin-dependent statistical γ-ray cascade model considering open nucleon emission channels even below the photoneutron threshold. Branching ratios of each step were determined using the optical statistical model and including pre-equilibrium contribution. The photoabsorption by the zero-particle–zero-hole (0p0h) ground state was assumed to excite 1p1h configurations. The calculations implied detailed knowledge on discrete levels up to a threshold energy (usually below 2 MeV), with energy, spin, parity values and transition probabilities taken from the literature, and a level continuum formalism above that. The de-excitation from the continuum was allowed through E1 transitions only. For lack of data, Lorentz parameters for natural isotopic mixtures or of neighbour isotopes were used in some cases.

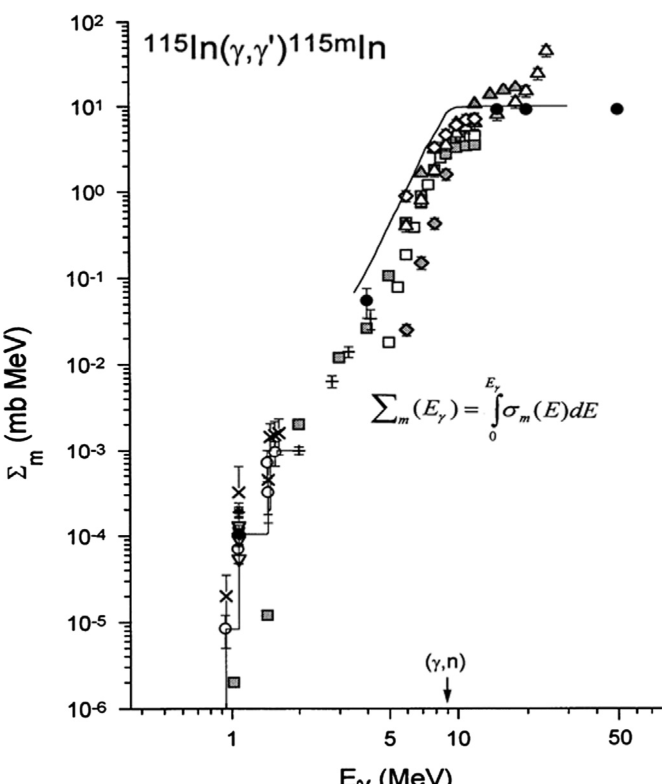

Fig. 1. Integrated cross section for $^{115}In^m$ production plotted as a function of photon energy. Data of the authors and co-workers are denoted with black full points, based on measurements of the isomer activities excited by ^{60}Co sources (Lakosi et al., 1974), 4 MeV endpoint energy (Lakosi, 1996), and 15–50 MeV endpoint energy bremsstrahlung (Sekine et al., 1991). Measured values overrunning saturated ones are of Goldemberg and Katz (1953) and Bogdankevich et al. (1956). References of other data are partly found in Ref. (Lakosi et al., 1992). The histogram corresponds to the increasing sums of cross sections integrated over individual activation levels, calculated on the basis of level parameters available in the literature. The curve in the continuum results from the model calculation (Lakosi et al., 1992, 1993/1).

For Se, Br, Kr, Tc, the resonance energy was estimated from systematics, the peak width was assumed to fit in the data for neighbouring nuclides, while the peak height was calculated to fulfill the Thomas-Reiche-Kuhn sum rule (Dietrich and Berman, 1988).

^{115}In is an archetypal nuclide in the photoexcitation of isomers as a test case. In Fig. 1 the integrated cross section of ^{115m}In excitation is seen as a function of the photon energy. The measurement data of the authors and co-workers gathered by irradiation with ^{60}Co sources (Lakosi et al., 1974), 4 MeV endpoint energy (Lakosi, 1996), and 15–50 MeV endpoint energy electron linacs (Lakosi et al., 1992, 1993/1) are displayed in black full points. Experimental results of others are also included. The histogram in the low energy region represents the growing sum of the integrated excitation cross sections calculated from the individual level parameters. As the energy grows up, the activation levels are getting more difficult to be identified (the level scheme above 1.6 MeV is incomplete, and unknown above 3.1 MeV). Treating the region above 4 MeV as a continuum, we performed gamma cascade calculations on the basis of level density formalism, in the frame of the statistical model, which resulted in the continuous curve (Lakosi et al., 1992, 1993/1).

The cross section spans 10 orders of magnitude from the first activation level at 597 keV up to 50 MeV. This indicates a kind of technical records at the same time, taking gamma spectra of natural indium samples of mass in the order of μg – 100 g. (The last amount was needed upon irradiation by a ^{137}Cs source, where a cross section of the order of 10^{-9} mbMeV was measured—this value is already outside the scale in the figure.)

Fig. 2 displays our measured and calculated integrated cross sections for the excitation of the ^{99m}Tc (Sekine et al., 1991; Lakosi

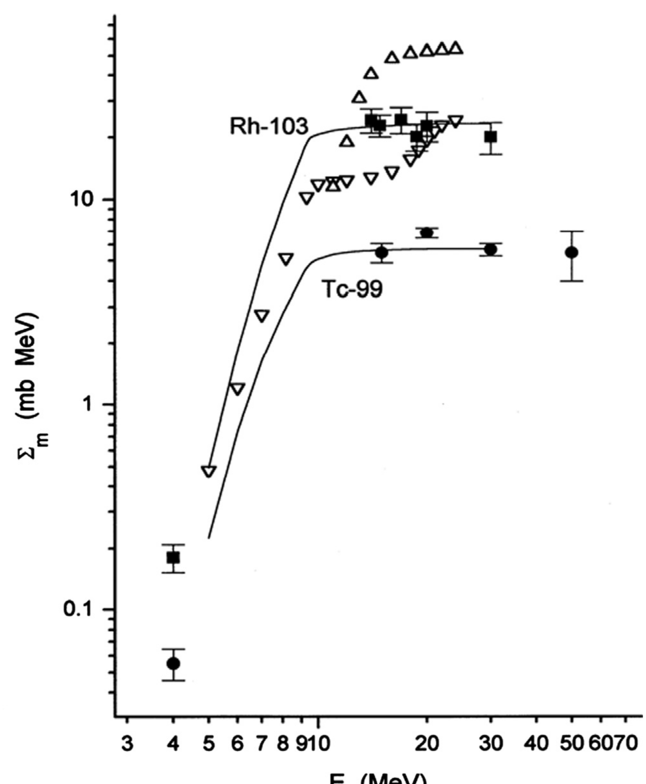

Fig. 2. Integrated cross sections for $^{99}Tc^m$ and $^{103}Rh^m$ production plotted as functions of photon energy. Data of the authors and co-workers are denoted with black full points, based on measurements of the isomer activities excited by 4 MeV (Sáfár et al., 1993; Lakosi, 1996) and 15–50 MeV endpoint energy bremsstrahlung (Sekine et al., 1991; Sáfár et al., 1991). The curves result from the model calculation (Lakosi et al., 1993/2; Sáfár et al., 1991). Measured values representing a second increase or bump in the GR region are of Del Rio y Sierra and Telegdi (1953) and Bogdankevich et al. (1960).