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Investigation of the Photon Strength Function in ^{130}Te

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Abstract. The dipole strength distribution of ^{130}Te was investigated with the method of Nuclear Resonance Fluorescence using continuous-energy bremsstrahlung at the Darmstadt High Intensity Photon Setup and quasi-monoenergetic photons at the High Intensity $\vec{\gamma}$-Ray Source. The average decay properties were determined between 5.50 and 8.15 MeV and compared to simulations within the statistical model.

1. Introduction

The properties of highly excited nuclei are important ingredients in astrophysical model calculations of the nucleosynthesis in stellar environments. In particular, Photon Strength Functions (PSF) for electric dipole ($E1$) and magnetic dipole ($M1$) transitions, respectively, are major input parameters for calculations of capture and photodissociation reactions. The PSF can be related to the photoabsorption cross section of atomic nuclei. In the last decades, the photoabsorption cross section has been investigated intensively, especially in the region of the Giant Dipole Resonance (GDR) [1]. Furthermore, for many nuclei additional low-lying $E1$ strength below and in the vicinity of the particle separation energies was observed, which is usually denoted as Pygmy Dipole Resonance (PDR) [2]. So far, the properties of the PDR have been mostly studied in closed-shell nuclei, e.g., in the Z=50 and N=82 mass region [2]. Therefore, the nucleus ^{130}Te was investigated via real photon scattering to extend the studies also to off-shell nuclei.

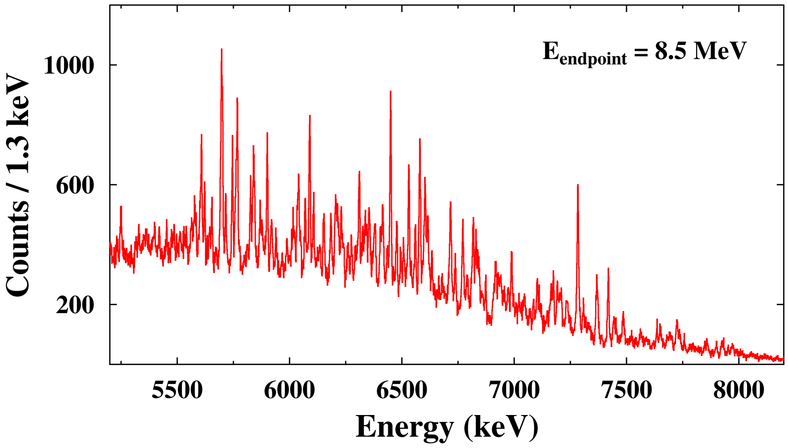

Figure 1. Spectrum of ^{130}Te measured at an endpoint energy of 8.5 MeV.

2. Experiments and preliminary results

Nuclear Resonance Fluorescence (NRF) experiments are well-suited to investigate the photoabsorption cross section below the neutron separation threshold [3]. Experiments with real photons are selective to dipole-excited states, therefore the NRF method was used to investigate the electric dipole response in ^{130}Te. One experiment was performed at the Darmstadt High Intensity Photon Setup (DHIPS) [4] using bremsstrahlung as the photon source. In Fig. 1 the measured spectrum for the endpoint energy of 8.5 MeV is shown. An accumulation of peaks in the spectrum originating from nuclear transitions were observed between 6 and 8 MeV.

To determine the absolute dipole strength, the nucleus of interest was simultaneously measured relative to a known calibration standard ^{11}B (for details see, e.g., Refs. [5, 6]). However, it is not possible to distinguish between $E1$ and $M1$ strength from these data. Therefore, an additional NRF experiment with quasi-monoenergetic and linearly polarized photons has been performed in the energy range from 5.5 to 8.5 MeV at the High Intensity $\vec{\gamma}$-Ray Source (HI$\vec{\gamma}$S) [7] at Triangle Universities Nuclear Laboratory, USA. Due to the linear polarization of the incoming photons it is possible to access parity information of the excited $J = 1$ states and, thus, to separate between $E1$ and $M1$ strength [8, 9]. In the case of ^{130}Te, excited states with negative parity were observed exclusively and therefore the measured dipole strength is assigned to be $E1$ strength.

Another advantage of the HI$\vec{\gamma}$S facility is the quasi-monoenergetic photon beam, which has a FWHM of about 3% of the mean beam energy. This allows for investigating average decay properties of nuclei as a function of the excitation energy [10]. The total photoabsorption cross section σ_{tot} can be determined by the sum of the contribution of photo-excited states that decay directly to the ground state (σ_{elast}) and from cascade transitions ($\sigma_{inelast}$).

This idea was presented, e.g., in Refs [10, 11, 12]. On the right side of Fig. 2 the measured spectrum for a mean beam energy of 7.85 MeV is shown together with the spectral beam distribution. Even though the incoming mono-energetic photon beam exclusively excites states in an energy range of a few hundred keV, decays of the first few excited 2^+ states were observed. This indicates that these excited levels are populated via cascade transitions of the initially excited states. An excitation and de-exciation scheme is shown on the left side of Fig. 2. It is commonly assumed that most of the intensity of cascading transitions (indicated as blue arrows) is collected in the first low-lying excited states (i.e., 2^+ states). Therefore, their decay intensities (indicated as green arrows) are used to estimate $\sigma_{inelast} \approx \sum_i \sigma_{2_i^+}$ (see Ref. [10]).

Preliminary results for σ_{tot} are shown on the left side of Fig. 3 together with data from a

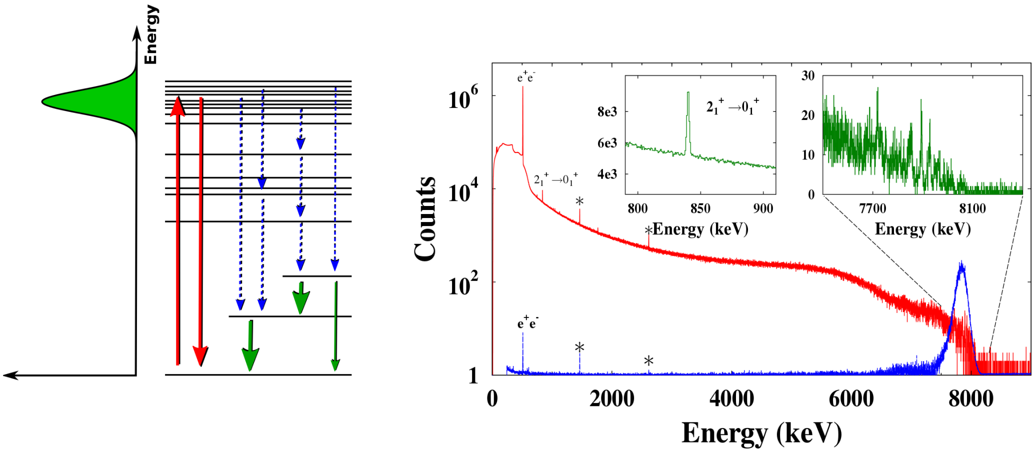

Figure 2. Left panel: Schematic example of the excitation and de-excitation process using a quasi-monoenergetic beam. Right panel: Spectrum of ^{130}Te measured at a mean beam energy of 7.85 MeV using the HI$\vec{\gamma}$S facility.

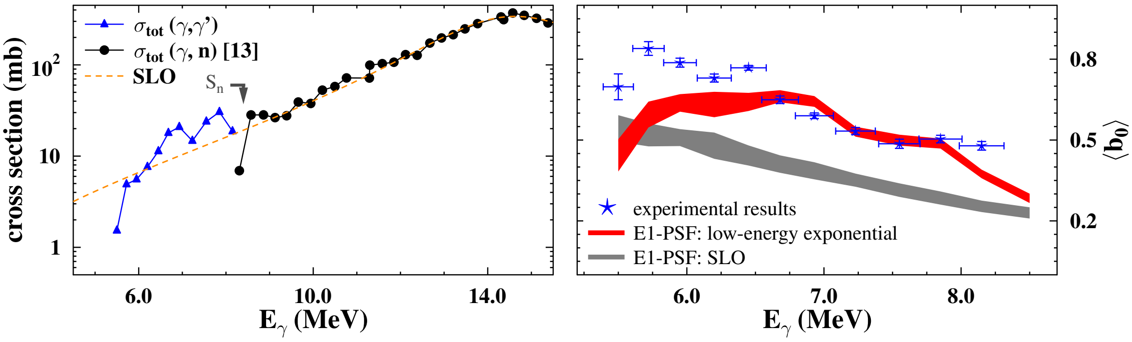

Figure 3. Preliminary results. Left panel: Photoabsorption cross sections for the energy range from 5.5 MeV up to 15 MeV. For details see text. Right panel: Experimental $\langle b_0 \rangle$ (blue stars) compared to DICEBOX simulations.

previous (γ, n) experiment at high energies [13]. An enhancement of the photoabsorption cross section between 6.5 and 8.0 MeV compared to the extrapolation of the GDR is observed. The PDR was observed in several other nuclei so far [2]. Using the extracted cross sections the average ground-state branching ratio $\langle b_0 \rangle = \sigma_{elast}/\sigma_{tot}$ was determined and is shown in the right panel of Fig. 3. The experimental data are compared to results obtained from statistical model simulations using the DICEBOX code [14]. The main input parameters in the simulations are the PSF for the transitions involved and the level density for the nucleus of interest. The two dominant PSFs are the $E1$- and $M1$-PSF. The Single Particle model was used for the $M1$-PSF while for the $E1$-PSF two different approaches were tested. The Standard Lorentzian (SLO) model as well as a model using the experimental data at $E_\gamma > 5.5$ MeV combined with a strong decrease to lower γ-ray energies. The backshifted Fermi-Gas model was used to describe the level density [15]. The SLO model is not able to describe the experimental results, which have higher values for $\langle b_0 \rangle$ at all energies. This observation indicates that the $E1$-PSF at low E_γ (for $E_\gamma \lesssim 3 - 5$ MeV) must be suppressed strongly with respect to the $E1$-PSF at $E_\gamma \gtrsim 3 - 5$ MeV than in the SLO model. Therefore, the other model was tested. It shows a better agreement, especially at $E_\gamma > 6.5$ MeV, even though it is not able to fully describe the experimental data at lower energies. It seems that the statistical model is not able to describe the decay properties of

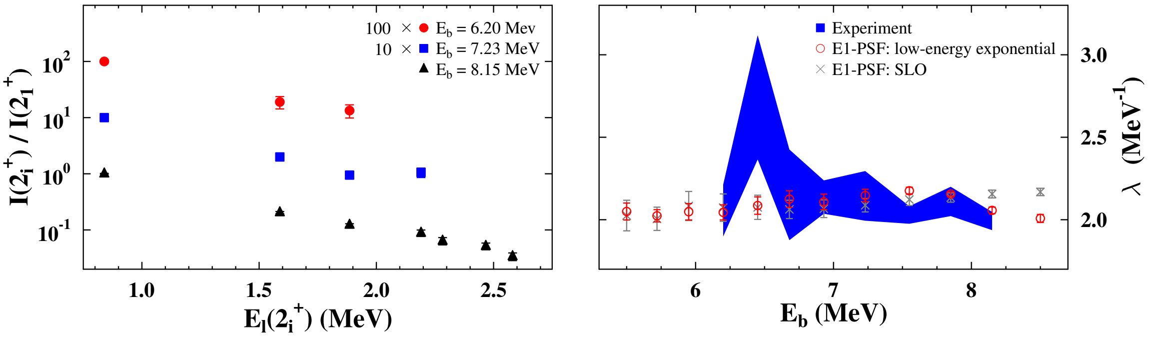

Figure 4. Preliminary results. Left panel: Relative population intensity of low- lying 2^+ states as a function of the level energy $E_l(2_i^+)$. The values for $E_b = 6.20$ MeV and $E_b = 7.23$ MeV are scaled by a factor of 100 and 10, respectively. Right panel: Exponential factor λ as a function of E_b.

^{130}Te at excitation energies below 6.5 MeV. This may indicate that contributions from nuclear structure effects have a significant impact even at rather high excitation energies [12].

As already mentioned, the first excited 2^+ states were populated by the photo-excited states. The population intensities of these states relative to the intensity of the 2_1^+ state as a function of their level energy $E_l(2_i^+)$ are shown for three beam energies E_b in the left panel of Fig. 4. All of them show an exponential behavior. Using an exponential fit function to describe the data ($\propto \exp(-\lambda \cdot E_l(2_i^+))$) the parameter λ can be extracted which serves as a signature for the corresponding function. The values for λ show a constant behavior as a function of E_b (see right side of Fig. 4). The DICEBOX simulations for both $E1$-PSF models show good agreement with the experimental data.

The combined results of both NRF experiments provide an extensive overview of the $E1$ strength distribution in ^{130}Te up to the neutron separation energy. The comparison of the experimental results to simulations in the framework of the statistical model using the DICEBOX code provides a new and deeper insight in the PSFs involved.

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3. References

[1] M. N. Harakeh and A. van der Woude, Giant Resonances (Oxford University Press, Oxford, 2001)
[2] D. Savran, T. Aumann and A. Zilges, Prog. Part. Nucl. Phys. **70**, 210 (2013)
[3] U. Kneissl, H. H. Pitz and A. Zilges, Prog. Part. Nucl. Phys. **37**, 349 (1996)
[4] K. Sonnabend *et al.*, Nucl. Instr. and Meth. Phys. Res. A **640**, 6 (2011)
[5] R. Schwengner *et al.*, Phys. Rev C **78**, 064314 (2008)
[6] D. Savran *et al.*, Phys. Rev. C **84**, 024326 (2011)
[7] H.R. Weller *et al.*, Prog. Part. Nucl. Phys. **62**, 257 (2009)
[8] N. Pietralla *et al.*, Phys Rev. Lett. **88**, 012502 (2002)
[9] J. Isaak *et al.*, Phys. Rev. C **83**, 034304 (2011)
[10] A.P. Tonchev *et al.*, Phys. Rev. Lett. **104**, 072501 (2010)
[11] C.T. Angell *et al.*, Phys. Rev. C **86**, 051302 (2012)
[12] M. Scheck *et al.*, Phys. Rev. C **87**, 051304(R) (2013)
[13] A. Leprêtre *et al.*, Nucl. Phys. A **258**, 350 (1976)
[14] F. Bečvář, Nucl. Instr. and Meth. Phys. Res. A **417**, 434 (1998)
[15] T. von Egidy, D. Bucurescu, Phys. Rev. C **80**, 054310 (2009)