Nuclear Inst. and Methods in Physics Research, A 899 (2018) 28–31

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Self-absorption with quasi-monochromatic photon beams

D. Savran [a,*], J. Isaak [b]

[a] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstr. 1, 64291 Darmstadt, Germany
[b] Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstr. 9, 64289 Darmstadt, Germany

ARTICLE INFO

Keywords:
Self-absorption
Nuclear resonance fluorescence
Gamma spectroscopy
Ground-state transition width

ABSTRACT

We present a new experimental technique to perform self-absorption experiments in combination with nuclear resonance fluorescence using a quasi-monochromatic photon beam for the determination of absolute level widths of excited low-spin states. By measuring simultaneously at two target positions the amount of absorbed photon intensity is directly measured in a single experiment, which strongly reduces systematic uncertainties and reduces the amount of needed beam time by a factor of two. In addition the method does not rely on a given shape of the energy profile of the photon beam and, thus, can also be applied with quasi-monochromatic beams produced via Laser-Compton-Backscattering (LCB). Due to the strongly reduced background with these kind of photon beams this new method in combination with LCB promises a highly improved sensitivity for self-absorption experiments compared to experiments using bremsstrahlung.

1. Introduction

The determination of absolute transition widths of excited states plays an important role in nuclear structure physics. They are directly related to transition probabilities and level lifetimes and, thus, are one of the basic properties to characterize nuclear excitations. Often they are particular sensitive to the structure of excited states and, therefore, are critical to know in the comparison to modern nuclear model calculations.

An experimental method to measure transition widths needs to fulfill two major requirements. First the observable needs to be sensitive to the corresponding transition width and, second, the nuclear reaction of choice needs to sufficiently populate the nuclear excitation of interest. For the latter, ideally the reaction does not only strongly populate the required excited states, but also suppresses the population of other excited states in order to reduce background contributions, i.e. is highly selective to the excitations of interest.

One field in nuclear structure physics that is currently of high interest is the investigation of $J = 1$ excitations below the particle threshold, in particular the scissors mode [1], two-phonon-states [2] and the Pygmy Dipole Resonance (PDR) [3]. An ideal reaction to selectively excite low-spin states is nuclear resonance fluorescence (NRF) [4]. Other strong advantages of this reaction are the model independent connection of measured cross sections to intrinsic properties of the excited states as well as an excellent energy resolution when combined with γ-ray spectroscopy using high-purity Germanium (HPGe) detectors. The combination of high-resolution and selective excitation allows to study modes such as the PDR on a state-to-state basis. In standard NRF experiments the cross section to excite the nucleus to a specific state and observe its decay back to the ground state is directly proportional to Γ_0^2/Γ with Γ_0 and Γ being the decay width to the ground state and the total width, respectively. The extraction of the wanted Γ_0 thus relies on the knowledge of the branching ratio to the ground state Γ_0/Γ, which is often difficult to determine especially in cases of higher level densities such as in the investigation of the PDR. The problem within the standard NRF technique arises from the fact that the number of reactions (and thus the cross section) is determined from the spectroscopy of the decay γ-rays. The excitation cross section itself is directly proportional to Γ_0. Thus, investigating the number of absorbed photons at a given resonance energy allows to directly determine the excitation cross section and by this Γ_0. This technique is called self-absorption [5–8].

1.1. The self-absorption technique

The basic idea of the self-absorption technique is very simple. Instead of determining the reaction cross section by counting the number of emitted photons after the excitation of the nucleus the absorption spectrum within the used photon beam is investigated. The difficulty is of course that bound nuclear resonances are usually very narrow (meV–eV) and absorption lines, thus, cannot be resolved by state of the art γ-ray detectors. In addition, any detector placed within the photon beam

* Corresponding author.
E-mail address: d.savran@gsi.de (D. Savran).

https://doi.org/10.1016/j.nima.2018.05.018
Received 12 April 2018; Accepted 9 May 2018

behind the NRF target will be flooded with unreacted photons of all photons outside of resonance energies. The solution for this problem is to use the nucleus of interest itself as a high-resolution detector, i.e. analyze the amount of absorbed photons within a first target (the *absorber*) by irradiating a second target of the same material (the *scatterer*) with the absorption spectrum. The more photons are (resonantly) absorbed at a give resonance energy within the absorber, the less reactions will take place within the scatterer. A measurement with only the scattering target and no absorber serves as the reference and it is possible to define the self-absorption R of a single resonance by

$$R = \frac{N_{abs} - N_{nrf}}{N_{nrf}} = 1 - \frac{N_{abs}}{N_{nrf}} \quad (1)$$

with N_{abs} and N_{nrf} being the number of reactions with and without the absorber, respectively. Beside the resonant nuclear absorption also atomic attenuation takes place in the absorber target, which needs to be accounted for. Of course also the total amount of incoming photons needs to be calibrated, i.e. the two experiments with and without absorber need to be properly normalized to each other. Recently, a new approach has been introduced by Romig et al. [9], that allows to normalize the photon flux as well as account for the atomic attenuation at the same time with strongly reduced systematic uncertainties. In both experiments a second material with suitable resonances, such as ^{11}B, is included in the scattering target but not the absorber, and is used as a reference. For the resonance energies of ^{11}B only atomic attenuation takes place in the absorber. Thus, by normalizing both measurements to the number of NRF reactions observed for ^{11}B not only the photon flux is calibrated but also the atomic attenuation is accounted for at the same time. This new approach of *relative self-absorption* by Romig strongly reduced the systematic uncertainties compared to previous self-absorption measurements using atomic absorbers with similar Z to determine the atomic attenuation [6–8]. However, the method requires the use of a broad energy spectrum of the incoming beam in order to simultaneously excite the states of interest and at least one resonance of the reference material. It is, thus, only applicable for bremsstrahlung photon beams and not for mono-energetic photon beams produced via Laser-Compton backscattering (LCB). In the following we present a new variation to perform self-absorption experiments in combination with LCB photon beams, which provides a number of advantages compared to experiments using bremsstrahlung. In addition, the presented method also reduces the amount of beam time by a factor of two.

2. Self-absorption with LCB photon beams

One of the drawbacks of self-absorption experiments using bremsstrahlung is the rather large background present in these experiments. In addition, since resonances in a large energy region are excited simultaneously feeding contributions might disturb the amount of self-absorption of lower-lying states. Also the complex detector response of HPGe detectors, such as single-escape and double-escape peaks, further complicate a precise analysis of the spectrum. These disadvantages are eliminated when using a quasi-monochromatic photon beam produced via LCB as for example at the High Intensity γ-ray Source (HIγS) [10] or the upcoming γ-beam facility at ELI-NP [11].

Fig. 1 shows as an example two NRF spectra for the nucleus ^{128}Te, one using a bremsstrahlung beam and one obtained with a LCB photon beam. The spectrum with bremsstrahlung was taken at the Darmstadt High Intensity Photon Setup (DHIPS) [12] at the S-DALINAC at TU Darmstadt with an endpoint energy of 9.13 MeV. The LCB spectrum was measured at the γ^3-setup [13] at HIγS at a centroid beam energy of 6.4 MeV and a FWHM of about 230 keV. In both cases also the energy profile of the incident photon beam is given.

It is evident, that for the LCB beam the background is strongly reduced to almost zero compared to the bremsstrahlung experiment, where peaks are sitting on a large background. In the latter case, the background is mainly originating from non-resonant processes in the target and, thus, is not correlated with the resonant excitation cross section and the peak intensities. For a measurement with absorber the peak areas will be strongly reduced, while the background will stay at the same level and, thus, will dominate the statistical uncertainty of the peak area determination. In addition, the complex detector response of the HPGe detectors is complicating the analysis and producing additional background due to the presence of single escape peak contributions, which are marked (asterisks) in the spectrum. Overall, using LCB beams as photon source for self-absorption experiments provides strong advantages to achieve higher precision. However, in combination with a LCB beam the normalization using a standard such as ^{11}B of the two measurements with and without absorber as introduced by Romig et al. is obviously not suitable in general due to the narrow bandwidth of the photon beam.

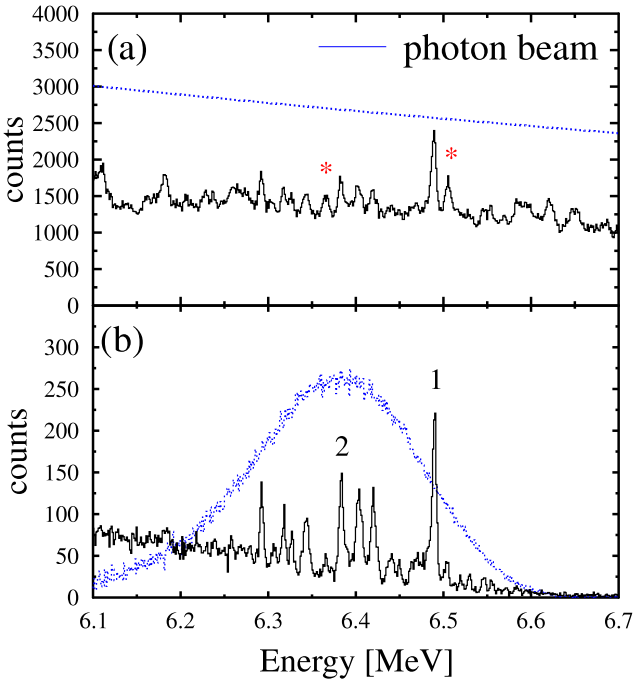

Fig. 1. NRF spectra for ^{128}Te(γ,γ') measured at DHIPS using bremsstrahlung (a) and at the γ^3-setup using a LCB photon beam (b). For both cases the energy profile of the incident photon beam is indicated by the dashed blue line.

In order to facilitate LCB beams to perform self-absorption experiments with small systematic uncertainties we propose the following technique. The idea and schematic setup is illustrated in Fig. 2. Instead of performing two single independent experiments with and without absorber both measurements are performed in parallel. At the first target position (T1) the unperturbed LCB photon beam irradiates a thin target of the isotope of interest, thus, a standard NRF experiment is performed. Behind T1 a thick absorber is placed into the photon beam producing the characteristic dips in the energy profile (as indicated in the figure) that are used in the self-absorption technique. In addition, the overall photon intensity is reduced by atomic attenuation in the absorber. This modified photon beam irradiates a second thin target at T2. Both setups need to be shielded from the absorber as well as from each other.

The difference in NRF reactions N_{T1} and N_{T2} for a given resonance measured at T1 and T2 is directly related to the self-absorption R by modifying Eq. (1) to

$$R = 1 - \frac{N_{T2}}{N_{T1} \times f}. \quad (2)$$

The normalization factor f is included to account for a proper normalization between the two measurements following the notation of Romig et al. in [9]. It combines all effects other than the resonant