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Electric dipole response in ^{120}Sn

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Abstract. In high-resolution $(\vec{p},\vec{p}')$ experiments under 0° the complete B(E1) strength distribution can be studied in stable nuclei. At the Research Center of Nuclear Physics in Osaka, Japan, the cross sections and observables for the polarization transfer of E1 and M1 excitations in ^{120}Sn were measured for scattering angles $\Theta = 0° - 4°$ in an excitation energy range of $5 - 25$ MeV. From the present measurement the complete B(E1) strength distribution and the branching ratios of the PDR to the ground state can be extracted. The experimental setup, the principle of backgound subtraction and first results on the E1 strength are presented.

1. Introduction

A strong effort in experimental and theoretical studies has been undertaken to understand electric dipole excitations in nuclei. Especially the resonance structure at excitation energies well below the Giant Dipole Resonance (GDR), often refered as Pygmy Dipole Resonance (PDR), presently attracts the attention of nuclear theorists and experimentalists (for a recent review see [1]). Its distribution typically has a centroid energy close to the neutron separation energy S_n and a total strength of 0.1-1% of the E1 energy-weighted sum rule. Although the existence of the PDR is known for a long time in stable nuclei, its origin is only poorly understood. In a variety of models, it is suggested to represent a vibration of the neutron skin against an isospin-saturated (N≈Z) core. Strong soft E1 modes have also been observed in exotic, very neutron-rich isotopes. There, the dipole response is characterized by a fragmentation of the strength distribution and its spreading to low energy regions, and by the mixing of isoscalar and isovector components. In neutron-rich nuclei investigations of the PDR are of high interest as a new structure phenomena and additionally for astrophysics, as it may have an impact on neutron-capture rates in the r-process nucleosynthesis.

The tin isotope chain is lately in the focus of experimental and theoretical investigations, as the available data provide a connection of stable and exotic nuclei and the dependence of characteristic properties of the PDR on the neutron excess can be studied systematically. There exist a broad range of microscopic calculations for tin isotopes [2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. Experiments on tin isotopes can cover a range of N/Z ratios from 1.24 to 1.64. Investigation of the systematics of the PDR in stable tin isotopes has been done for ^{116,124}Sn in Gent [12] and for ^{112,120}Sn at the S-DALINAC in Darmstadt [13] using the technique of nuclear resonance flourescence (NRF). The dipole strength distributions and E1 response below the GDR of the neutron-rich nuclei $^{129-132}$Sn have been measured at GSI using Coulomb excitation with highly relativistic radioactive beams in inverse kinematics [14, 15].

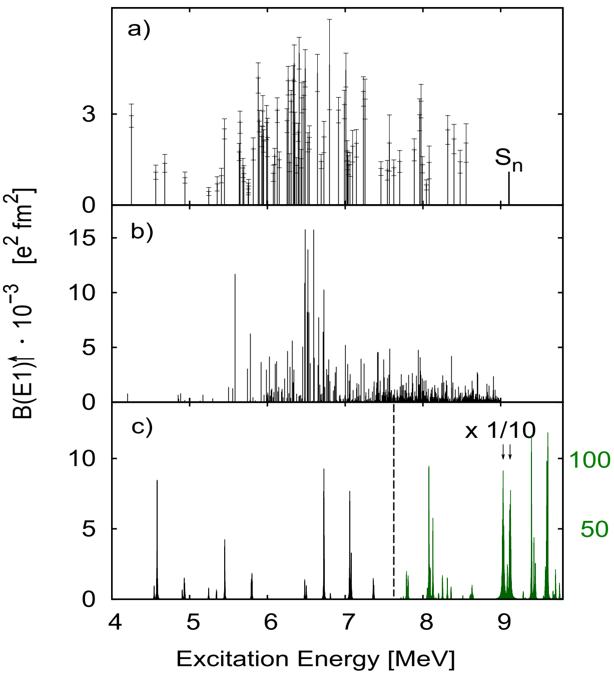

Figure 1. Comparison of the B(E1) strength in ^{120}Sn from a (γ,γ') experiment a) QPM b) and RQTBA c) calculations. S_n indicates the position of the neutron separation energy. Note the different axis for transitions on the r.h.s. of the dashed line in c).

Fig. 1 shows a comparison of the B(E1) strength of ^{120}Sn(γ,γ') measured at the S-DALINAC using the technique of NRF [13, 17] with calculations based on the nonrelativistic quasiparticle phonon model (QPM) [18] and relativistic quasiparticle time blocking approximation (RQTBA) [19]. For the QPM calculation the mean field is determined by a Woods-Saxon potential whose parameter are taken from a global parameterization and levels near the Fermi surface are adjusted to experimental values. The QPM calculation include one-, two and three-phonon states. The RQTBA is an extension of the self-consistend relativistic quasiparticle random-phase approximation, where a fully consistent calculation scheme based on a covariant energy density functional theory is used. It includes only a subspace of all 2-phonon states with structure (1 phonon x 1p-1h) and no 3-phonon states. Whereas the qualitative description is comparably, the predictions differ strongly in the absolute values of B(E1).

With NRF it is possible to study the B(E1) strength with a high energy resolution. However, this technique is experimentally limited as the measured cross sections depend on the ground-state decay branching ratio, which is unknown and therefore typically assumed to be 100%. In particular, the PDR can only be studied at exitation energies roughly up to the particle emission threshold.

From this study it was concluded that knowledge of the complete E1 response would be important to differentiate between relativistic an nonrelativistic QRPA models predicting largely different properties of the pygmy dipole resonance. Within recent experimental progress an experimental test of the different models is possible. One method without these limitations is (p,p') scattering, where the complete B(E1) strength can be determined. Whereas in (γ,γ') scattering only E1 can be excited, also M1 excitations are expected in (p,p') scattering due to nucleon-nucleus interaction. As M1 excitations goes along with a spin flip transition, measurements with polarized protons provide a tool to distinguish between these two types of excitations. In this paper, we report the experimental method of proton scattering at forward angles and recent preliminary results.

2. Experimental Method

2.1. Experimental Setup

A polarized proton beam is accelerated up to 295 MeV by the azimuthally varying field (AVF) and RING cyclotrons, and then transported through the WS beam line to the target chamber of the Grand Raiden (GR) magnetic spectrometer. A typical degree of polarization of 70 % can be achieved. The scattered protons are momentum-analyzed with the high-resolution spectrometer Grand Raiden (GR) [20]. Its focal plane detectors [21] consist of two multi-wire drift chambers (MWDCs), two plastic scintillators and the Focal Plane Polarimeter (FPP). The FPP [22] measures the polarisation of the scattered prtons and consists of four MWDCs, a carbon block and two hodoscopes. When the polarized protons pass through a carbon analyzer, the nuclear spin-orbit force leads to an azimuthal asymmetry in scattering from carbon nuclei. The particle trajectories, in particular the scattering angles in the carbon, are determined by pairs of drift chamber in front and behind the carbon block. Scattering processes for polarized protons from ^{12}C are well known, so that one can draw conclusions from the angular distribution of the protons behind the carbon block on the polarization of the scattered protons. Measurements have been performed for 0°, 2.5°, 4°. A tin foil isotropically enriched to 98.39% ^{120}Sn with a thickness of 6.5 mg·cm^{-2} was used as a target. In order to achieve an energy resolution up to 25 keV tuning of the beam is essential. Therefore angular und dispersion matching techniques were applied [23]. The experimental setup for proton inelastic scattering measurement at zero degrees is shown in Fig. 2. The left side shows the setup with sidewards polarized beam, whereas the right hand side is for a longitudinally polarized beam. We chose mildly under-focusing optics in non-dispersive direction for the background subtraction described below. The ion-optical parameters were calibrated by analyzing the data with a sieve slit at the entrance of the spectrometer measured at 16°. The ion optical parameters for the vertical scattering angle were very sensitive to the vertical beam position on the target. The Large Acceptance Spectrometer (LAS) was used for monitoring the vertical beam position on the target. A detailed description of the setup for 0° measurements can be found in [24].

2.2. Background Subtraction

Even in a measurement with a very clean beam, there still exists instrumental background. The background particles are mostly caused by multiple Coulomb scattering in the target followed by scattering at the inner part of the spectrometer. The contributions of background events in the measured spectra could be experimentally determined by the following method: Vertical trajectory of particles determined by MWDCs were projected onto the vertical focal plane

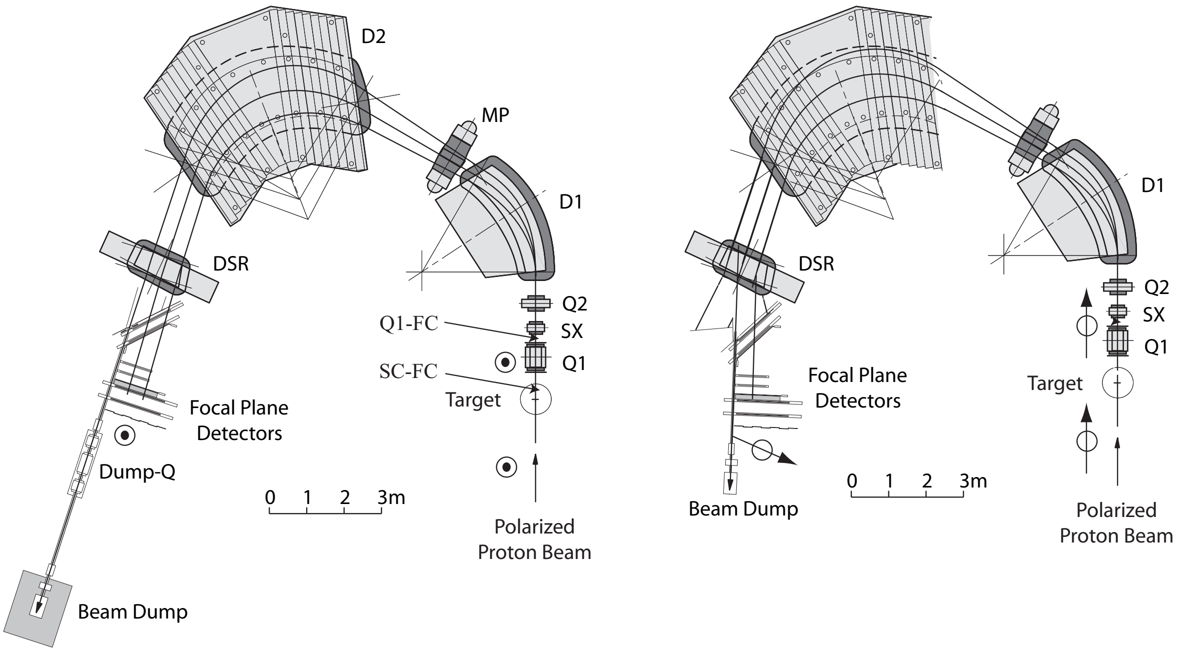

Figure 2. Setup for polarization measurement at 0° for sidewards and longitudinally polarized beams at the Research Center of Nuclear Physics in Osaka

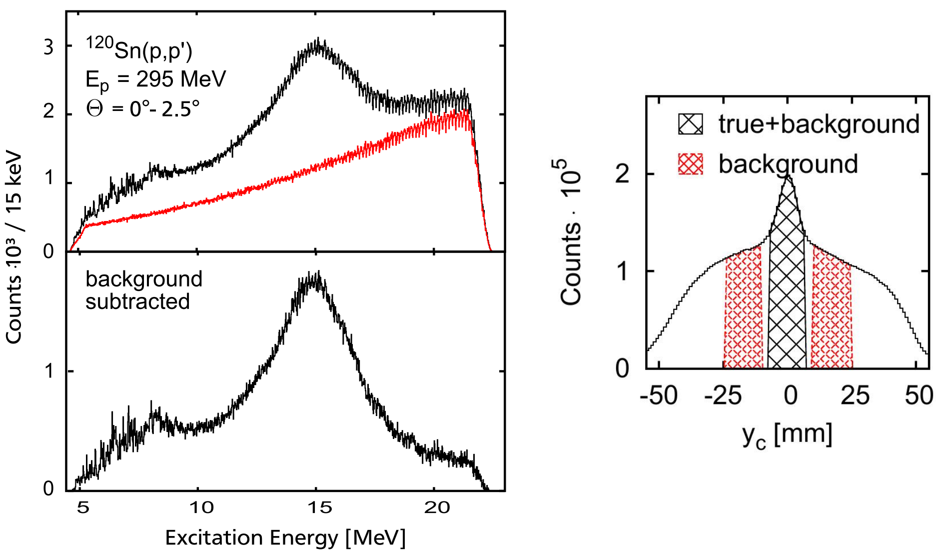

Figure 3. Spectrum of the ^{120}Sn(p,p′) reaction at $E_p = 295$ MeV and at a spectrometer angle $\Theta = 0° - 2.5°$ and method of background subtraction

as shown in the right part of Fig. 3. Since true events focussed around the vertical beam position y_c=0, the outer area is considered to consist solely of background events. Assuming a flat background distribution in the center part, the shape and the heigth of the background spectrum can be obtained. In the upper left part of Fig. 3 the black line shows all events, whereas the lower red curve shows only events which are in the background area. After subtracting the background spectrum, excitation energy spectra free from instrumental background are obtained. A detailed description on the analysis procedure is given in [25].

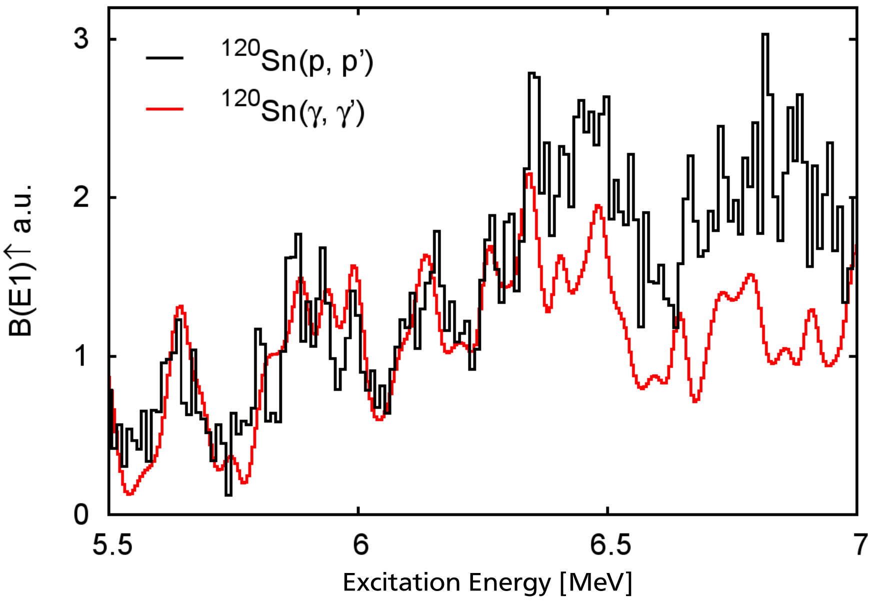

Figure 4. Comparison of the excitation energy spectra with (γ,γ') experiment at the energy region of 5.5–6 MeV

3. Spectra and Results

The excitation energy spectrum of the ^{120}Sn is shown in the lower left part of Fig 3. The broad bump is located around an excitation energy of 15 MeV is identified as the GDR. Between 5 and 10 MeV resonance structure is visible, which is expected to be mostly due to E1 strength.

Since ^{120}Sn has been measured with the nuclear resonance flourescence method at the S-DALINAC [13], a comparison with the (p,p') for the low energy region is shown in Fig. 4. For that purpose the spectrum of the (γ,γ') experiment, which had an energy resolution of few keV, was folded with a Gaussian width ΔE= 30 keV (FWHM), which corresponds to the energy spread in the (p,p') experiment. Both spectra are corrected for their corresponding efficiency and incident particle flux. When scaled to a peak at 5.6 MeV, both spectra agree well up to 6.5 MeV, suggesting that the observed (p,p') cross section is indeed due to Coulomb-excited E1 transitions. Between 6.5 and 7 MeV, qualitatively the same structures are visible, but the smaller (γ,γ') result indicates that decay branching to excited states become relevant. The strong suppression at higher energies may be due to several effects: strong branchings to states other than the ground state, decreasing sensitivity of the (γ,γ') experiment and/or strong contributions of the M1 spin-flip resonance in the (p,p') data.

4. Summary

In summary, the paper presents a high-resolution $(\vec{p},\vec{p}')$ experiment on ^{120}Sn with an incident energy of 295 MeV and at forward angles including 0°. The necessary analysis steps to optimize the energy resolution and to perform a model independent background subtraction are shown. The qualitative comparision with previous (γ,γ') experiments and calculations suggests such reactions to be a promising tool for the study of complete B(E1) strength distribution in nuclei. Further analysis is necessary to extract the differential cross sections. Combining the measurements using longitudinal and sidewards polarized protons a separation of the (p,p') cross section into nonspin-flip E1 and spin-flip M1 excitations can be achieved by measuring the polarisation transfer observables D_{SS} and D_{LL} [22]. Independently E1 and M1 strengths can be distinguished by a multipole decomposition of angular distributions including 0°. The extraction of the complete B(E1) strength will be a test of the various theoretical models and will lead to a better understanding of the pygmy dipole resonance.

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