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Structure of the Pygmy Dipole Resonance

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1. Experiment Summary

We propose an experiment to test a new excitation mechanism to study the pygmy dipole resonance (PDR) which is a concentration of energetically low-lying $J^{\pi}=1^{-}$ states located below the very well-known giant dipole resonance (GDR). The PDR is presently topic of numerous experimental and theoretical works. In a first test we would like to study the ^{143}Nd(p,dγ)^{142}Nd reaction with an incident proton energy of E_p=9 MeV which is just below the Coulomb barrier. In this way, the fusion-evaporation channels will be strongly suppressed, allowing the direct mechanism to manifest. The aim of the proposed experiment is to populate the states of the PDR in ^{142}Nd and to measure the emitted deuteron in coincidence with the γ decay of the excited states in ^{142}Nd. In the case of an effective excitation of the PDR by means of this proposed reaction, a possibly new excitation mechanism can be established which allows complementary measurements to study the PDR and its decay in great detail.

2. Introduction

Around the $1\hbar\omega$ region a concentration of electric-dipole strength, the commonly denoted pygmy dipole resonance (PDR), can be found in many atomic nuclei. High-resolution photon scattering experiments have revealed details of the strength distribution of this mode in various semi-magic nuclei [1-7]. The summed strengths exhaust up to 1% of the isovector energy weighted sum rule (IVEWSR). A similar mode has been found just above the particle threshold in neutron-rich exotic nuclei [8-10]. The connection to the low-lying *E1* strength is still unclear and is presently investigated intensively. The observed concentration of collective non-statistical strength close to the particle threshold is not only an interesting nuclear structure phenomenon, but has an important impact on the nucleosynthesis in explosive stellar burning phases [11-13] as well. Here, extrapolations to very proton-rich systems based on reliable data on nuclei in the valley of stability are needed. The planned experiment is closely related to experiments on exotic nuclei performed at GSI and planned for FAIR within the R3B project. Furthermore, the superior properties of ELI will improve the sensitivity of the experiments by at least one order of magnitude which allows for the investigation of the PDR in deformed nuclei. In addition, the PDR is related to the equation of state of neutron-rich matter as well as the neutron-skin thickness of neutron-rich nuclei and exotic objects in the universe like neutron stars [14-16].

Various, sometimes contradictory model descriptions exist to account for the origin of the *E1* strength. The approaches include e.g. hydrodynamic and collective models [17, 18], density functional calculations [19], quasiparticle random phase approximations [20, 21], calculations in the quasiparticle-phonon model [6, 22, 23], and calculations in the extended theory of finite Fermi systems [4, 24, 25]. The models predict different isospin character of the PDR. Some recent theoretical calculations give a possible explanation for the splitting of the PDR which we observed in recent experiments. We have performed a couple of $(\alpha,\alpha'\gamma)$ coincidence experiments at the Big-Bite Spectrometer (BBS) at the Kernfysisch Versneller Instituut (KVI) in Groningen, The Netherlands, to investigate the PDR in the N=82 isotones ^{140}Ce and ^{138}Ba, the Z=50 isotope ^{124}Sn, the non-magic nucleus ^{94}Mo and the double-magic nucleus ^{48}Ca [26-28]. The obtained *E1* distribution patterns of these experiments are quite different from the ones measured for the same nuclei in real photon scattering experiments. In all investigated nuclei a pronounced splitting of the PDR into two parts has been observed: One part that is excited in $(\alpha,\alpha'\gamma)$ and (γ,γ') reactions, and one part that is only excited in (γ,γ'), as shown in figure 1. This points to different underlying structures of the two parts which has been interpreted recently within a relativistic mean field approach. The lower-lying group of states seems to represent the more isoscalar neutron-skin oscillation which is typical for the PDR. On the other hand, the higher-lying states apparently belong to a transitional region on the tail of the GDR [28]. These experiments have shown that comparing different experimental techniques is a powerful tool to study the underlying structure of an excitation mode like the PDR. The proposed ^{143}Nd(p,dγ)^{142}Nd experiment might provide important new data for further complementary experiments and by this will help to achieve a deeper understanding of the nature of the PDR.

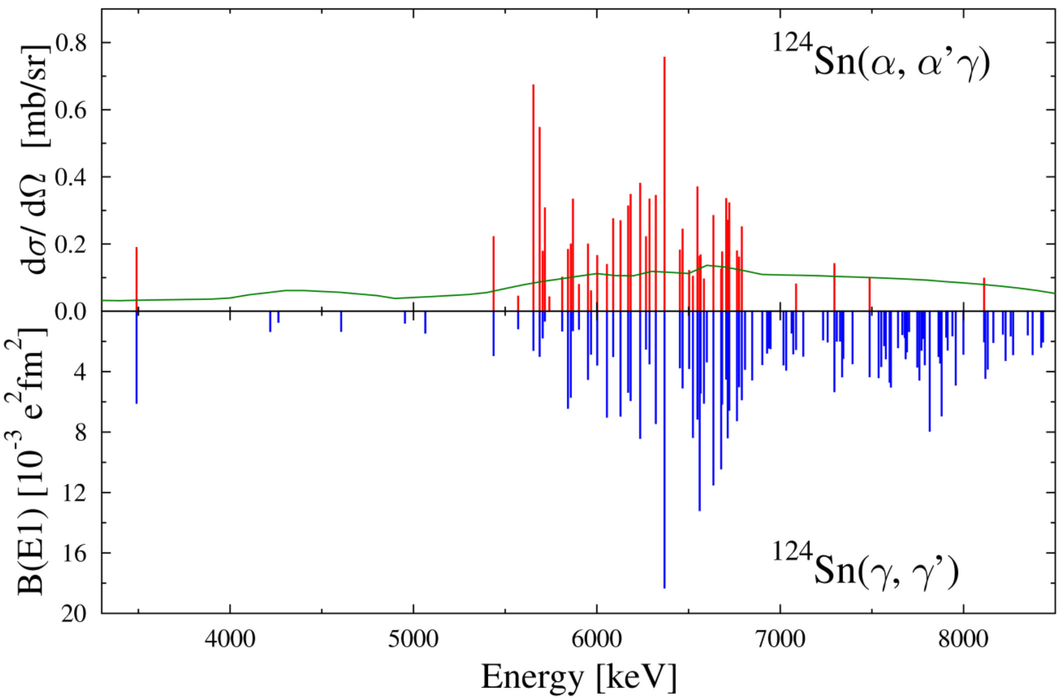

Figure 1: Results of the (α,α'γ) (upper row) and (γ,γ') (lower row) experiment on ^{124}Sn [28]. The green line represents the experimental sensitivity limit. Up to about 6.8 MeV almost all states could be excited in both kinds of experiments while the energetically higher-lying states could only be excited in (γ,γ').

3. Experiment Description

We propose to perform the ^{143}Nd(p,dγ)^{142}Nd reaction to study the PDR in ^{142}Nd which has been investigated by means of the (γ,γ') method, see figure 2 [6]. To measure the decay of the PDR in ^{142}Nd we would like to use the high-purity germanium (HPGe) detector array at IFIN-HH in the experimental hall 1. In order to distinguish between transitions stemming from the PDR and other transitions from excited states in the target a coincident measurement of the emitted deuteron is crucial. This coincidence technique allows us to gate on ground state transitions which is the dominant decay channel of the PDR. The excitation energy can be deduced from the residual energy of the deuterons. Therefore, a ΔE-E silicon detector needs to be installed to discriminate the (in-)elastically scattered protons. A large area and segmented detector provided by the IFIN-HH would improve the setup and therefore the sensitivity a lot.
The proton energy would be chosen to be E_p=9 MeV which is just below the Coulomb barrier. Here the fusion evaporation channels are strongly suppressed [29]. The Q-value for this reaction is -3.9 MeV and the intensity of the proton beam will be I≈50 nA.
Because this kind of experiment has never been done before to populate the PDR, this proposed experiment is a test of a new excitation mechanism. The cross sections have been estimated using the DWBA code CHUCK [30]. While the total cross section for a (p,d) reaction (E_p = 9MeV) is calculated to be σ=0.2mb the cross section for proton scattering is about a factor of 67 larger which is reasonable to discriminate the protons in the ΔE-E detector.

Taking the efficiency of the setup into account, an estimation of the expected coincidences stemming from the PDR can be done.
Therefore, we request 120 hours (15 shifts) of beam time for the proposed experiment to gain about 300 events distributed over several peaks stemming from the PDR. The target material will be provided and prepared by the University of Cologne.

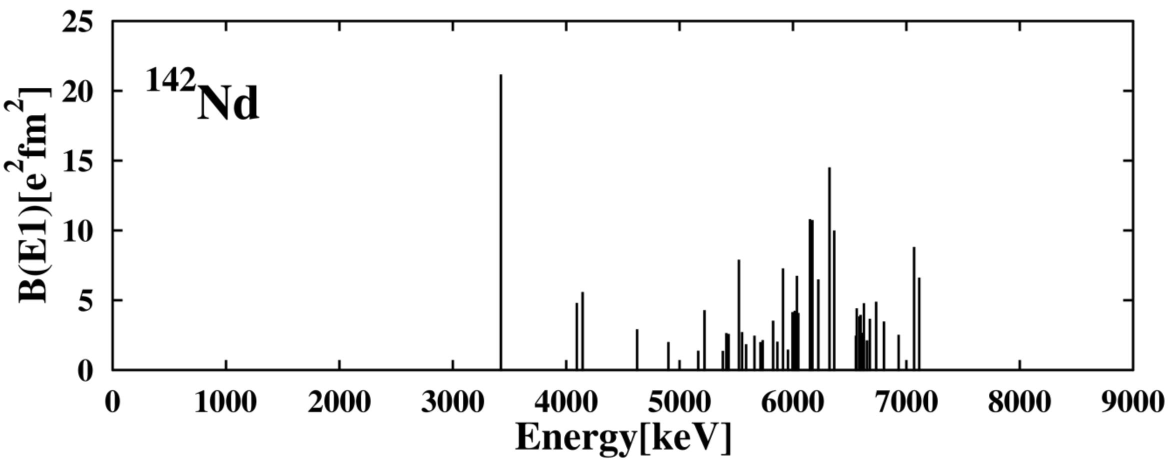

Figure 2: Results of the (γ,γ') experiment on ^{142}Nd [6]. The *B(E1)* strength is shown as a function of energy and the PDR between 4 MeV and 7 MeV is clearly visible.

References

[1] T. Hartmann et al., Phys. Rev. Lett. 85 (2000) 274; Erratum: Phys. Rev. Lett. 86 (2001) 4981.
[2] T. Hartmann et al., Phys. Rev. C 65 (2002) 034301.
[3] A. Zilges et al., Phys. Lett. B 542 (2002) 43.
[4] T. Hartmann et al., Phys. Rev. Lett. 93 (2004) 192501.
[5] A. Zilges et al., Prog. Part. Nucl. Phys. 55 (2005) 408.
[6] S. Volz et al., Nucl. Phys. A779 (2006) 1.
[7] D. Savran et al., Phys. Rev. Lett. 100 (2008) 232501.
[8] P. Adrich et al, Phys. Rev. Lett. 95 (2005) 132501.
[9] A. Klimkiewicz et al., Nucl. Phys. 788 (2007) 145.
[10] O. Wieland et al., Phys. Rev. Lett. 102 (2009) 092502.
[11] D. L. Lambert, Astron. Astroph. Rev. 3 (1992) 201.
[12] T. Rauscher, F.-K. Thielemann, At. Data Nucl. Data Tables 75 (2000) 1.
[13] P. Mohr et al., Phys. Lett. B 488 (2000) 127.
[14] J. Piekarewicz, Phys. Rev. C 73 (2006) 044325.
[15] A. Klimkiewicz et al., Phys. Rev. C 76 (2007) 051603(R).
[16] C. J. Horowitz and J. Piekarewicz, Phys. Rev. Lett. 86 (2001) 5647
[17] F. Iachello, Phys. Lett. B 160 (1985) 1.
[18] Y. Suzuki et al., Prog. Theor. Phys. 83 (1990) 180.
[19] J. Chambers et al., Phys. Rev. C 50 (1994) R2671.
[20] G. Colò et al., Phys. Lett. B 485 (2000) 362.
[21] N. Paar et al., Rep. Prog. Phys. 70 (2007) 691.
[22] N. Tsoneva et al., Phys. Lett. B 586 (2004) 213.
[23] N. Tsoneva and H. Lenske, Phys. Rev. C 77 (2008) 024321.
[24] V. Tselyaev et al., Phys. Rev. C 75 (2007) 014315.
[25] G. Tertychny et al., Phys. Lett. B 647 (2007) 104.
[26] D. Savran et al., Phys. Rev. Lett. 97, 172502 (2006).
[27] J. Endres et al., Phys. Rev. C 80, 034302 (2009).
[28] J. Endres et al., Phys. Rev. Lett. 105 (2010) 212503.
[29] E. Rademacher et al., Nucl. Phys. A620 (1997) 151.
[30] P.D. Kunz, Program CHUCK, University of Colorado, unpublished.