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COLLECTIVE DIPOLE EXCITATIONS IN NEUTRON-RICH NUCLEI FROM ^{132}Sn MASS REGION, THE NUCLEAR SYMMETRY ENERGY AND NEUTRON SKINS*

A. Klimkiewicz[a], N. Paar[c], P. Adrich[a,b], M. Fallot[b]
K. Boretzky[b], T. Aumann[b], D. Cortina-Gil[d]
U. Datta Pramanik[a], Th.W. Elze[e], H. Emling[b], H. Geissel[b]
M. Hellström[b], K.L. Jones[b], J.V. Kratz[f], R. Kulessa[a]
C. Nociforo[b,f], R. Palit[e], H. Simon[b], G. Surówka[a]
K. Sümmerer[b], D. Vretenar[c], W. Waluś[a]

[a]M. Smoluchowski Institute of Physics, Jagellonian University
Reymonta 4, 30-059 Kraków, Poland
[b]Gesellschaft für Schwerionenforschung (GSI), 64291 Darmstadt, Germany
[c]Physics Department, University of Zagreb, Bijenička 32, 10000 Zagreb, Croatia
[d]University of Santiago de Compostela, 15706 Santiago de Compostela, Spain
[e]Institut für Kernphysik, Goethe Universität, 60486 Frankfurt, Germany
[f]Institut für Kernchemie, Gutenberg Universität, 55099 Mainz, Germany

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Dipole strength distributions measured in unstable neutron-rich nuclei in the ^{132}Sn mass region by utilizing relativistic Coulomb excitation of radioactive beams reveal a sizable fraction of "pygmy" strength below the giant dipole resonance. On the grounds of the RQRPA model, a strong linear correlation between the pygmy strength, parameters of the nuclear symmetry energy and the neutron skin thickness has been found. From the experimentally observed low-lying strength, the symmetry energy pressure $p_0 = 2.3 \pm 0.8$ MeV/fm^3 and neutron skin thicknesses of 0.23 ± 0.04 fm in ^{130}Sn and 0.24 ± 0.04 fm in ^{132}Sn have been extracted.

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1. Introduction

Heavy nuclei with a large neutron excess develop a neutron skin which is an outer coat of neutron-rich nuclear matter around the core. The formation of the neutron skin is driven by the density dependence of the nuclear

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symmetry energy [1]. According to theoretical predictions, the neutron skin can oscillate against the core of a nucleus, giving rise to a new collective mode called pygmy dipole resonance (PDR), which manifests itself as a concentration of dipole strength around the neutron separation threshold [2, 3]. A clear experimental evidence for the PDR could deliver valuable information on both neutron skin size and the equation of state of asymmetric nuclear matter [4]. In this contribution we demonstrate a way to determine the neutron skin thickness in unstable neutron-rich ^{130,132}Sn and to constrain parameters of the symmetry energy by means of measured dipole strength distributions [5, 6].

2. Experimental setup

The measurement was performed at the GSI facility, Darmstadt, with the LAND-FRS experimental setup [5]. Radioactive ions were produced by means of in-flight fission of primary ^{238}U beam at 550 MeV/nucleon. Isotopes with a mass-to-charge ratio similar to that of ^{132}Sn were selected from other products in the fragment separator FRS and transported to the LAND experimental area. Projectiles were directed onto a $^{\mathrm{nat}}$Pb target and excited electromagnetically to dipole states including the giant dipole resonance (GDR). The experimental setup was optimized for detection of all outgoing reaction products that emerge after projectile's dissociation, mostly neutrons and γ-rays, measured with almost full acceptance and very high efficiency. Excitation energy was reconstructed by combining four-momenta of all outgoing projectile-like particles in the invariant-mass analysis with a resolution of $\sigma_E \approx 1$ MeV above the neutron separation threshold.

3. Experimental results

The measured Coulomb excitation (Coulex) cross-sections, as shown in Fig. 1, consist of two components — a high energy part which corresponds to the GDR and an additional low-energy shoulder right above the neutron separation threshold [5,6]. In order to gain insight into this low-lying dipole strength, the contribution from parameterized GDR and instrumental effects were subtracted from the energy-differential Coulex cross-sections. The GDR in the investigated nuclei can be well described by a single Lorentzian distribution in the photoabsorption cross-section with parameters that agree with systematics of stable nuclei. Since the systematics parameters remain almost constant for the narrow mass range of the studied isotopes, within experimental resolution the same set of parameters was adopted with resonance energy $E_0 = 15.5$ MeV, width $\Gamma = 4.7$ MeV and photoabsorption cross-section $\sigma_\gamma = 2150 \pm 140$ mb MeV [6]. The low-lying dipole strength appears in considered ^{130,132}Sn isotopes and exhausts a few percent of the energy-weighted sum rule. Such high values indicate either concentration of many single-particle transitions in a narrow energy range [3] or emergence of a new "soft" collective mode [2]. The measurement, however, does not deliver a definite answer to the question about the nature of the observed low-energy excitations.

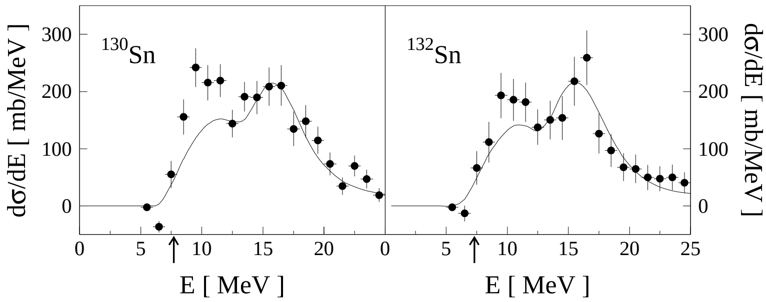

Fig. 1. Coulomb excitation cross-sections measured in ^{130,132}Sn. Solid lines represent parameterized GDR folded with detector response. The cross-section excess in the low-energy part cannot be attributed to neither GDR nor instrumental effects. The arrows indicate the location of the neutron separation threshold.

A comparison of the measured low-lying dipole strength with available data in stable nuclei reveals a clear trend of strength increasing with the neutron–proton asymmetry and tends to support the theoretically expected correlation between the pygmy strength and the nuclear symmetry energy which is directly related to the formation of the neutron skin. To explore this relation in a more quantitative way, a series of fully self-consistent RHB+RQRPA calculations of ground-state properties and dipole strength distributions has been performed [2]. The density dependence of the symmetry energy has been varied by changing the parameterization of the effective DD–ME interactions used as a basis for theoretical modelling [7].

The calculation gives an almost linear correlation between the symmetry energy parameters a_4 and p_0, the predicted neutron skin size and the pygmy strength in neutron-rich ^{130,132}Sn isotopes, as shown in Fig. 2. The experimental ratios of PDR to GDR strength could be translated by means of the theoretical relation into corresponding p_0 values. The average value of $\bar{p}_0 = 2.3 \pm 0.8$ MeV/fm^3 was finally used to derive neutron skin thicknesses of 0.23 ± 0.04 fm in ^{130}Sn and 0.24 ± 0.04 fm in ^{132}Sn [6]. Using the identical symmetry energy parameterization we performed the same analysis for stable ^{208}Pb in order to verify the adopted approach. The low-lying strength was taken from [8]. Deduced neutron skin thickness of 0.18 ± 0.035 fm remains in very good agreement with independent measurements [9, 10].

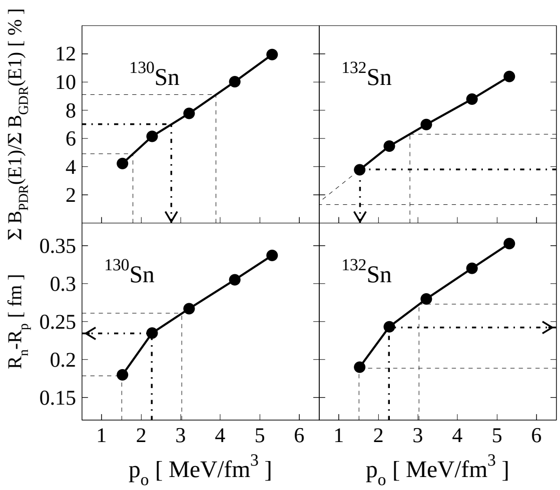

Fig. 2. Upper row: calculated ratios of GDR to PDR strength for ^{130,132}Sn *versus* symmetry energy pressure p_0 (circles and the solid lines). The dashed lines show experimental counterparts with errors and deduced range for p_0 values. Bottom row: theoretical relation between neutron skin thickness and p_0. The dashed lines "translate" the average p_0 value into the neutron skin thicknesses with errors.

Studies of new collective modes in unstable nuclei provide a novel tool to investigate properties of asymmetric nuclear matter reflecting the density dependence of the symmetry energy. The correlation between the pygmy strength and parameters of the symmetry energy should be verified, however, on the grounds of various microscopic models.

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