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Study of the isoscalar giant monopole resonance: Discrepancies between available experimental results

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Summary. — Over the last four decades, the isoscalar giant monopole resonance (ISGMR) was extensively studied worldwide, especially at the Texas A&M University (TAMU) Cyclotron Institute, the Research Center for Nuclear Physics (RCNP) and recently at the iThemba Laboratory for Accelerator Based Sciences (iThemba LABS), South Africa, through small angle (including 0°) inelastic α-scattering measurements at 240, 386, and 196 MeV, respectively. In all the available datasets published by the different facilies, noticeable differences in the isoscalar giant monopole (IS0) strength distributions were observed. This paper focuses only on the two extreme cases: the light deformed ^{24}Mg and the heavy spherical ^{208}Pb to summarize discrepancies between the different results.

1. – Introduction

The isoscalar giant monopole resonance (ISGMR) was extensively studied since its discovery in the late 1970s due to its role in constraining the incompressibility of uniform nuclear matter (K_∞) [1, 2]. Most of the results on the study of the ISGMR emanates mainly from the Texas A&M University (TAMU) Cyclotron Institute and the Research Center for Nuclear Physics (RCNP). Besides cases where different systematic trends of

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the incompressibility of nuclei (K_A) are extracted from datasets obtained at these two facilities [3-6], an independent investigation of the IS0 strength in nuclei across a wide mass range was performed using the 0° facility at iThemba Laboratory for Accelerator Based Sciences (iThemba LABS), South Africa, to highlight differences observed between IS0 strength distributions in previous experiments [7]. In that study, we emphasized the different methods and energy ranges used to extract the centroid energy of the ISGMR, which leads to a range of values of the ISGMR centroids reported in literature. For the case of ^{90}Zr and ^{208}Pb, this particularly has an impact on the extracted values of the nuclear matter incompressibility from the comparison to random-phase approximation (RPA) calculations with different forces. Recently, it has been shown that calculations including coupling to complex configurations could help resolving the longstanding problem that the RPA calculations require a significantly lower value of K_∞ to describe the Sn isotopes than ^{208}Pb [8,9]. The comparison of the theoretical results to a particular set of experiments may render the conclusions emanating from these studies non exhaustive.

The IS0 strength distributions in the prolate ^{24}Mg has been investigated at iThemba LABS through $\alpha-$particle inelastic scattering measurements with a beam of 196 MeV. The main goal of the study was to investigate the two-peaked structure of the strength distribution due to the coupling of the ISGMR and the $K = 0$ component of the isoscalar giant quadrupole resonance (ISGQR) in deformed nuclei. The coupling between the two modes results in a double peak structure of the isoscalar monopole (IS0) strength (a narrow low-energy deformation-induced peak and a main broad ISGMR part). The energy of the narrow low-lying IS0 peak is sensitive to both K_∞ and the coupling between IS0 and isoscalar quadrupole (IS2) strength [10]. The results obtained from the study were compared with previous experimental datasets from TAMU [11] and RCNP [12]. While the iThemba LABS results agree reasonably well with the TAMU results, there is a noticeable discrepancy with the RCNP datasets.

Here, we aim to summarize the observed discrepancies seen between available ISGMR datasets. We will focus only on the two extreme cases: the light deformed ^{24}Mg ($\beta = 0.613$) and the heavy spherical ^{208}Pb.

The paper is organized as follows: in sect. **2**, a summary on the experimental details on the datasets under review is given. The method of extraction and the resulting IS0 strength distributions are presented in sect. **3** while, in sect. **4**, some conclusions are drawn.

2. – Experimental details

The details of the experimental procedure followed to extract the IS0 strength distribution in ^{24}Mg and ^{208}Pb at the different facilities are fully described in refs. [7,10-14]. As such, only the main points for iThemba LABS are summarized here. The experiment was performed at the Separated Sector Cyclotron (SSC) facility with a beam of 196 MeV α-particles inelastically scattered off self-supporting ^{24}Mg and ^{208}Pb targets with areal densities 0.23 and 1.4 mg/cm^2, respectively and isotopically enriched to values $> 96\%$. The reaction products were momentum analyzed by the K600 magnetic spectrometer positioned at laboratory scattering angles 0° and 4°. The IS0 strength distributions were obtained by means of an excitation-energy-dependent Difference-of-Spectra (DoS) technique (see refs. [7, 10]). For TAMU and RCNP, see details in refs. [11-14].

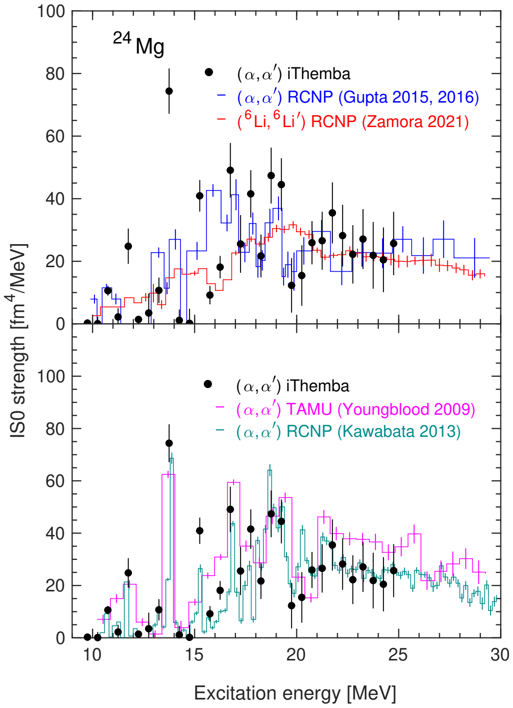

Fig. 1. – IS0 strength distributions in ^{24}Mg obtained at iThemba LABS (black filled circles), RCNP (blue, red and dark cyan histograms) and TAMU (magenta histogram) (taken from [10]). The top panel shows comparison between iThemba LABS [10] and RCNP [12, 16] results while bottom panel shows comparison with RCNP [15] and TAMU [11].

3. – Results and discussion

Over the years the multipole-decomposition analysis (MDA) technique has been one of the most reliable tools used to extract multipole strength distributions in nuclei, including the isoscalar giant monopole [2]. In the study conducted at iThemba LABS, the DoS method [17] was chosen over MDA due to the limitation in availalable angular datapoints (0° and 4°) since the primary goal of the study was to investigate the fine structure of the ISGMR in some key nuclei accross the nuclear chart. IS0 strength distributions in ^{24}Mg and ^{208}Pb obtained at the three facilities are shown in figs. 1 and 2. It can be seen that the three datasets broadly agree with one another for the ^{24}Mg results (fig. 1). However, the data from TAMU, above 17 MeV is consistently higher than the datasets from iThemba LABS and RCNP (bottom panel of fig. 1). This is a known feature from TAMU data and is often attributed to their empirical background-subtraction method. On the other hand, the IS0 strength distributions from iThemba LABS [10], TAMU [11] and RCNP [15] are somewhat different that the one from RCNP [12] and [16] in region below 15 MeV. The narrow low-energy deformation-induced peak in the RCNP dataset [12] occurs at about $16-18$ MeV and two times lower than the other (α,α') results (top panel of fig. 1). It

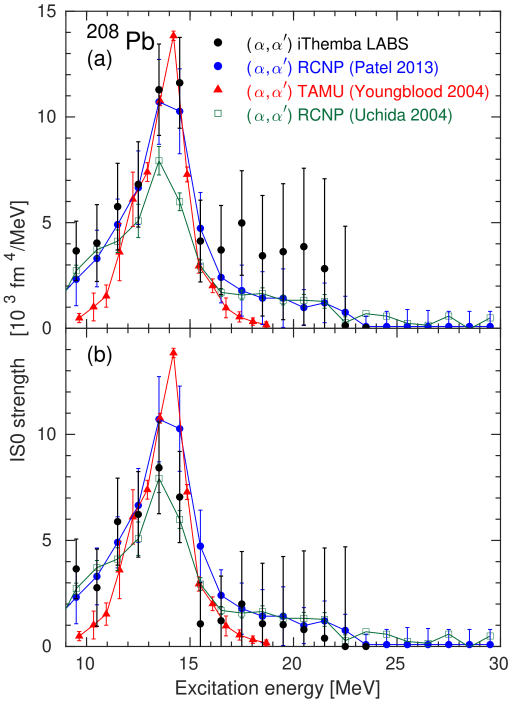

Fig. 2. – Same as fig. 1 but for ^{208}Pb. Results from iThemba LABS are shown as black filled circles while the ones from RCNP are shown as blue filled circles, dark green open squares and from TAMU as red filled triangles (taken from [7]). The top and bottom panels show comparison between iThemba LABS [7], RCNP [13, 18] and TAMU [14] results.

is worth noting that the datasets in ref. [15] (dark cyan histogram in bottom panel of fig. 1) were taken at RCNP with higher energy resolution and the results were published before the ones (blue histogram in top panel of fig. 1) in ref. [12]. The energy location of the deformation-induced peak is very important as this peak arises due to the IS0/IS2 coupling in deformed nuclei and its energy value is sensitive to the incompressibility K_∞ and isoscalar effective mass m_0^*/m values (see ref. [10] for details).

The IS0 strength distributions in ^{208}Pb at iThemba LABS are compared with datasets from RCNP [13, 18] and TAMU [14] groups (figs. 2). Top panel shows the iThemba LABS results when fraction energy-weighted sum rule (FEWSR) from RCNP are used to correct the small-angle spectrum while bottom panel displays results when FEWSR from TAMU are used to correct the small-angle spectrum (see ref. [7] for details). It can clearly be seen that the datasets show different structures in the strength distribution. While the TAMU results yield a very narrow and symmetric strength distribution with the highest strength at the peak of the ISGMR, the datasets from RCNP lie in between with their maximum peak slightly lower than that of TAMU. Agreement of the iThemba LABS results with any of the other datasets also depends on the source of the correction factors used in the application of the DoS method (see ref. [7] for details). It is also interesting to notice the difference in the strength distributions of the two RCNP datasets [13, 18]. While they both peak roughly at the same position, the strength value of the dataset in [13] is 1.5 times higher than that of ref. [18]. These structural differences affect not only the extracted centroid energy values but consequently the incompressibility K_∞ value.

4. – Conclusions

In this study, we present the different available ISGMR datasets from the three major facilities that extensively studied the isoscalar giant monopole strength distributions in a wide range of nuclei accross the nuclear chart. We focus on the two extreme cases ^{24}Mg and ^{208}Pb where significant structural differences were noticed in the strength distributions. The impact of these differences on the centroid energy values and hence on the extraction of the nuclear matter incompressibility was highlighted which then opens a room for the need of new high-precision data on key nuclei for an accurate determination of the nuclear matter incompressibility.

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