Study of compression modes in 56Ni using an active target

Bagchi, Soumya

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2015

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.
Chapter 7

Summary and outlook

Summary

With the advent of new types of accelerators, it is nowadays possible to access nuclei with exotic neutron-to-proton ($N/Z$) ratios in the nuclear chart. How the structure and properties of a nucleus, especially its collectivity, change with exotic ($N/Z$) ratios is still one of the fundamental questions in the field of nuclear physics. In fact, the study of collective modes in stable nuclei, the so-called Giant Resonances (GR), has been one of the physics motivations throughout the history of nuclear physics. Among these collective modes, the Isoscalar Giant Monopole Resonance (ISGMR) and the Isoscalar Giant Dipole Resonance (ISGDR) are of prime interest as their excitation energies are directly related to the nuclear incompressibility of a finite nucleus. The nuclear incompressibility of nuclear matter can be defined as the curvature of the binding energy per particle at the saturation density. It is an important key input to the equation of state of nuclear matter which, in turn, is useful in understanding some astrophysical phenomena such as masses of neutron stars and supernovae explosions.

Among the collective modes of a nucleus, an isoscalar mode refers to the oscillations of protons and neutrons in phase whereas an isovector mode refers to the oscillations of protons and neutrons out of phase. The ISGMR and ISGDR can be studied via inelastic $\alpha$-particle scattering as the $\alpha$-particle has its spin and isospin both equal to zero. The main motivation of this thesis is to study the ISGMR and ISGDR in $^{56}\text{Ni}$ with inelastic $\alpha$-particle scattering, although the ISGMR and Isoscalar Giant Quadrupole Resonance (ISGQR) in $^{56}\text{Ni}$ have been previously studied via inelastic deuteron scattering [53]. Since $^{56}\text{Ni}$ is an exotic (neutron-deficient) unstable nucleus, it cannot be used as a target. Therefore, we have performed
our experiment in inverse kinematics. Dealing with exotic beams is very challenging; as the intensity of such beams is very low, so to get a reasonable yield, a thick target is needed. However, the usage of a thick target can degrade the energy resolution and very low-energy recoil particles may not come out of the target. A storage-ring facility where the luminosity of the exotic beam can be increased by accumulation and circulation of the beam in the ring, for example the ESR at GSI, is a good alternative. Another approach is to use an active target - a gas detector where the target gas also acts as a detector. Such an example is the MAYA active-target detector.

We have performed our experiment at GANIL in Caen, France in May, 2011. The main aim is to study the ISGMR and ISGDR in $^{56}$Ni with inelastic $\alpha$-particle scattering using the active target MAYA with a beam energy of 50 MeV/u. MAYA is a time-charge projection chamber, which was filled, in our experiment, with 95% He and 5% CF$_4$ at a pressure of 500 mbar. Since the GR state of a nucleus is above the particle-emission threshold, $^{56}$Ni will decay by emitting mainly protons and $\alpha$-particles. These decay particles are very forward focused and will not stop inside the MAYA volume as they have almost the same energy per nucleon as the beam. To detect these particles, additional Si-CsI telescopes have been placed in the forward direction. Details of the $^{56}$Ni beam-production method from the stable $^{58}$Ni primary beam, the existing facility at GANIL and the experimental setup of the MAYA active-target detector are given in Chapter 3.

Data analysis has been performed using the ROOT framework. The $^{56}$Ni-beam selection and the geometrical and event-reconstruction selection conditions for the recoil $\alpha$-particles are detailed in Chapter 4. The data analysis has been performed on an event-by-event basis. In order to understand the detector efficiency and acceptance, extensive simulations have been performed using the inputs from the LISE++ \cite{78} and SRIM \cite{61} software packages. The details are given in Chapter 5.

For a complete understanding of the GR structures, the angular distributions have to be reconstructed. To obtain the absolute cross sections, elastic-scattering of $\alpha$-particles from $^{56}$Ni has been studied. The angular distributions of giant resonances have been obtained in two different ways. The first method is the Gaussian peak-fitting method, where the events are considered for a given center-of-mass (CM) angle to obtain the excitation-energy spectrum for that angle. The peaks in the obtained excitation-energy spectra are fitted with Gaussian functions and the areas of these Gaussian functions will then lead to the angular distributions. However, a background has to be subtracted beforehand.

The nature of the GR states can also be deduced from another independent analysis which is
called the Multipole-Decomposition Analysis (MDA). In this case, the events are considered for a given excitation-energy interval to obtain the angular distribution for that excitation energy. The obtained angular distributions for each energy interval are then fitted with a linear combination of theoretical cross sections of multipoles relevant to the energy interval under consideration. The theoretical differential cross sections were calculated within the Distorted-Wave Born Approximation (DWBA) framework using the CHUCK3 code [59].

In both methods, the existence of the $L = 0$ mode (ISGMR) of $^{56}$Ni was established. The peak position of the monopole mode obtained from the Gaussian peak-fitting method is found to be at $19.1 ± 0.5$ MeV whereas the value obtained from the MDA is found to be at $18.4 ± 1.8$ MeV. The FWHM values obtained from the Gaussian peak-fitting method and the MDA are $2.0 ± 0.3$ MeV and $2.0 ± 1.2$ MeV, respectively. Both the results (centroid position and FWHM of the monopole mode) are consistent with each other within the error bars.

The fingerprint of the low-lying dipole ($L = 1$) mode in $^{56}$Ni has been found both in the Gaussian peak-fitting method and in the MDA at an excitation energy around 17 MeV. As expected, the dipole strength increases at high excitation energies, leading to the high-energy component of the bi-modal nature of the ISGDR strength. The bi-modal nature of the ISGDR has also been found in $^{58}$Ni with the low-lying peak appearing around 16 – 17 MeV and the high-energy component around 30 MeV [50, 52]. In this analysis, the evolution of the ISGDR strength in the $^{56}$Ni data has been found to be, more or less, similar to the predictions obtained from the Hartree-Fock based Random-Phase-Approximation calculations [80] although the percentage of energy-weighted sum rule (EWSR) exceeds 200% which is hardly physical. This could be due to the lack of knowledge in background subtraction.

The presence of the $L = 2$ mode (ISGQR) in $^{56}$Ni has also been found although the centroid position appears at least 2 MeV lower than what has been found for $^{56}$Ni with inelastic deuteron scattering [53]. However, the root-mean-square (rms) width of the strength distribution was found to be consistent with results for almost all other Ni isotopes found in different experiments [50].

For excitation energies higher than 20 MeV, the octupole mode ($L = 3$) also starts contributing as MDA suggests.

From the centroid value of the monopole mode, it is possible to calculate the nuclear incompressibility ($K_A$) for a finite nucleus using Eqn. 2.15. The rms radius ($\sqrt{\langle r^2 \rangle}$) of the charge distribution for $^{56}$Ni can be approximated by that for $^{58}$Ni. From the Fermi charge-distribution model, the rms value of the radius of the charge distribution for $^{58}$Ni is given as 3.764(10) fm [83]. The value of $K_A$ for $^{56}$Ni thus obtained from the Gaussian peak-fitting
method is 125.1(4.4) MeV whereas from MDA, the value of $K_A$ has been calculated to be 116.0(11.5) MeV.

**Outlook**

This thesis presents the analysis of an experiment which aimed to study the compression modes in $^{56}$Ni with inelastic $\alpha$-particle scattering. For this purpose, we have used the active-target detector MAYA. During the experiment and data-analysis, a number of challenges have been faced. In future, when performing experiments with such an experimental setup, these challenges have to be kept in mind and it is necessary to take actions accordingly. Few points for further improvements of such experimental setup and operating conditions are mentioned below.

Since MAYA is a time-charge projection chamber, the pressure of the gas inside MAYA has to be kept as low as possible for a two-body reaction where both the heavy and light particles have traces on the cathode pads. This will ensure that, most of the recoil particle will come out of the beam region and therefore, can easily be detected. It can be seen from the present analysis that, the long recoil-particle tracks have better resolution in the reconstructed range, energy and scattering angle as compared to the short recoil-particle tracks. Short recoil-particle tracks are difficult to reconstruct as they are closer to the beam region. If the pressure of the gas-mixture inside MAYA is low, most of the recoil-particle tracks will fall under the long-tracks category leading to better results. However, for lower gas pressure, the target will get thinner and therefore, the yields of the reaction of interest will go down. Therefore, the pressure of the gas mixture should be adjusted at the optimum value. Another alternative is to make the active target longer.

If the pressure is low, then the recoil particles having high energies will punch through the MAYA volume. This will lower the acceptance of the detector. Therefore, to solve this problem, MAYA should be surrounded with solid-state detectors to detect the particles that punch through and measure their energy loss and/or energy deposited in the ancillary solid-state detectors.

A proper beam monitor should be installed inside the MAYA chamber. This will ensure the proper counting of the number of incoming beam particles. Although in our experiment there was a diamond detector to monitor the incoming beam particles, it was unfortunately not working during the experiment. Therefore, no information could be extracted from it except using it as a beam dump.
The granularity of the cathode pads also determines the resolution of the extracted range of the recoil particle tracks. In MAYA, the cathode pads are hexagonal in shape with the length of the sides as 5 mm. However, in the future type of active targets, such as ACTAR [70], the cathode pads are smaller in size (2 mm and square in shape) and, therefore will, lead to better resolution of the reconstructed kinematics variables. This will improve the angular resolution which is important in the study of cross sections in the minima.