EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

Investigating single-particle configurations in deformed Hg and Cd isotopes

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Estimated beam time: about 4 days, split into 1 day for ^{194}Hg and 3 days for $^{109-113}$Cd
Beamline: XT02 (ISS/SpecMAT) or XT03 (ACTAR TPC)

Abstract

We propose to take advantage of the stable or long-lived isotope beams available during the second long shutdown of ISOLDE to study the single-particle configurations of the deformed nuclei. In particular, we focus on the long-live isotopes of $^{193\text{-}195}$Hg close to the shape-coexistence region, and the even-mass neutron-rich isotopes of $^{112\text{-}118}$Cd. In these nuclei, the deformation leads to the fragmentation of the single-particle strength in several deformed states. We propose to use one-neutron transfer reactions using an active target detection system coupled to γ-ray detectors to study the single-particle occupation of the low-energy excited states. Scintillation detectors will be used to perform coincidence gate on charged particles from the transfer reactions. Reconstruction of the angular distribution in the active target will provide both the angular momentum and the spectroscopic factor of the excited states. The centroid of the effective single-particle energies will then be determined and compared to shell-model calculations.

Physics cases

Excited states in $^{193\text{-}195}$Hg

It is now well-established that neutron-deficient Hg isotopes are deformed: $^{180\text{-}186}$Hg demonstrate a phenomenon of shape coexistence, when deformed intruder states descend in excitation energy along with the ground state band [1], but the deformation takes place all along the isotopic chain of Hg. Following on the deformation of the nucleus, we observe fragmentation of the single-particle strength in several Nilsson orbitals. Their relative energies and their ordering depends on the parameter of deformation in the nucleus.

With N=113 and 115, the spin-parity of the ground and excited single-particle states of ^{193}Hg and ^{195}Hg only depends on the valence neutron. This makes them particularly attractive cases for identification of the neutron single-particle states and to follow the evolution of the corresponding effective single-particle energies with the shape variations. Apart from a 13/2+ isomers, several other low-J excited states have been measured[2,3], but spectroscopic factors still suffer of uncertainties. Also, it was observed that the relative energy between the first 1/2- and 3/2- excited states increases as neutrons are removed in the Hg isotopic chain[4]. This can be explained as a consequence of the deformation of the nucleus, and as the appearance of a new subshell closure in oblate nuclei, N=120.

To probe the neutron-hole states in ^{193}Hg, we propose to perform a one-neutron stripping reaction. Both (p,d) and (d,t) reaction will be performed in inverse kinematics with a beam of ^{194}Hg. The two different targets will be used in order to populate excited states with different transferred angular momentum. Particle states in ^{195}Hg will be populated by one-neutron pick-up (d,p) experiments. Spectroscopic factors of the different populated states will allow to determine the centroid of the effective single-particle states of the (i13/2, p3/2, f5/2) orbitals in the valence space. The effective single-particle energies will then be compared with the shell-model calculations under development in that region[5].

Single-particle configurations in even Cd

As in Hg isotopes, Cd nuclei are subject to deformations and intruder states tend to appear at low energy[6]. The energy of the $0+_2$ in the neutron-rich isotopes have already been measured through various experiments and show the same parabola trend as in the Hg chain. Recent shell-model calculations have shown that the neutron configurations of the $0+_1$ (ground state) is mainly coming from the filling of the neutron d5/2 and the g7/2[7]. However, it appears that for its $0+_2$ state, the neutron h11/2 starts to be significantly filled from ^{108}Cd (N=70) to more neutron-rich Cd isotopes. [7]

We propose to perform a systematic study of the second 0+ states in the even-mass isotopes of Cd, using (d,p) and (α,^{3}He) in inverse kinematics. Long-lived ^{109}Cd or stable beams of beams of $^{111-113}$Cd would be used. Population of the $0+_2$ state of ^{112,114}Cd[8,9] has already been performed using one-neutron (d,p) transfer reactions, and provided information on the neutron configuration. If cross sections are too low for the $0+_2$ in heavier isotopes, we still expect to populate low-energy excited states, and constrain shell model calculations by determining the centroid of the effective single-particle energies.

In addition, we intend to perform a two-neutron transfer (α,^{2}He) in inverse kinematics, with a ^{116}Cd beam. Two-neutron transfer reactions have been successfully used to populate deformed $0+_2$ state in lighter even-mass nuclei [10,11]. In ^{118}Cd, several states around 1.5 MeV have been identified as good candidates[12], and the two-neutron transfer experiment proposed in this letter would permit to complete the systematic of the measurements of $0+_2$ in the even-mass Cd isotopic chain described above.

Experimental setup

One of the challenges of such study is the ability to identify the populated excited states and to obtain the angular cross section with a good resolution over a wide angle. With an angular resolution of 1 degree, and an angular coverage of about 4π, the active target and time projection chamber are perfectly suited for this kind of experiment. Currently, for these experiments, we consider using one of the two active targets available: ACTAR TPC[13], in its final phase at GANIL, and SpecMAT, which is under construction at KU Leuven.

Gases of D_2 and He will be used as targets. The trajectories of the charged particles emitted in the transfer reaction will be reconstructed in 3 dimensions following the time-projection chamber principle, giving complete information on the reaction kinematics. From previous experiment performed with the ACTAR-TPC demonstrator[14], we can confirm a spatial resolution of less than 2 mm.

In addition to the ACTAR-TPC gas detector, an array of several Si detectors will be positioned around the active volume in order to perform particle identification and to measure total energy. Alternatively, in the case of the SpecMAT detector, the setup will be placed in the ISS solenoid, providing a strong magnetic field of 3T. The reconstruction of the kinematics and the particle identification will be performed using the magnetic rigidity. Which of the active targets will be used, will depend upon luminosity and efficiency considerations that will be simulated for each case, and upon the availability of the instruments.

Independently of the active target, we will use the scintillation detector array as designed and developed for SpecMAT. Because of the exceptional precision on the reaction vertex, the Doppler correction applied on the γ-ray energy would allow to perform gates on the angular distribution of charged particles emitted in coincidence. These experiments (and in particular on Hg isotopes) will be used for the commissioning of the scintillator array and the SpecMAT active target itself, in order to characterize their resolution and efficiency.. At 1 MeV, the detection efficiency of the scintillation detectors array of SpecMAT is about 7%. In the case of Hg isotopes, these measurements will benchmark the performance of the instrument in view of the investigation of the more exotic neutron-deficient isotopes around $^{180-186}$Hg.

Estimated beam time

Long-lived or stable beams yields available at ISOLDE have not been yet measured, except for ^{194}Hg. The only limiting factor in the experiments described above is the number of particles at the entrance of the device. To optimize the live time and avoid pile-up effects, the beam intensity should not exceed 10^5 pps in the active volume (10^6 for SpecMAT). The length of the active volume of the final detector will be about 25 cm. In the following beam request, we take a conservative efficiency of the active target and reconstruction of 90%.

In the case of Hg isotopes, a very rough estimate of the cross section can be extrapolated from previous transfer experiment ^{200}Hg(p,d)^{199}Hg. If we assume a total cross section of about 12 mb, a gas of D_2 at 1 bar in the active target, the rate of transfer reactions is about 5.10^3 per hour. Based on that estimation, only a couple of shifts per nucleus would be necessary to measure the states we are interested in.

For Cadmium isotopes, we base our beam request on previous (d,p) experiments performed in inverse kinematics and using beam of ^{111}Cd[8] and ^{113}Cd[9]. The average total cross section for populating the second 0+ state in both ^{112}Cd and ^{114}Cd is 0.05 mb. Using gases of He and D_2 in the active-target volume at 1 bar leads respectively to 11 and 22.3 events per hour. In a couple of days per nuclei, we would obtain reasonable statistical uncertainties on the angular distribution and compare it with DWBA calculations.

Several shifts should however be added to take into account the tuning of the beam and of the detectors. If we assume one shift per nucleus, 4 shifts are added to the total estimated beam request

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