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High-precision spectroscopy of ^{65}Ni via neutron capture

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Summary. — Detailed studies of the low-spin structures of neutron-rich Ni isotopes may help shedding light on the shape coexistence phenomenon. Of particular interest is the ^{65}Ni nucleus, since it lies between ^{64}Ni and ^{66}Ni, where shape coexistence has been reported earlier. A spectroscopic investigation of ^{65}Ni has been performed at Institut Laue-Langevin via the reaction ^{64}Ni(n,γ)^{65}Ni, using the FIPPS HPGe array. Several new gamma transitions have been observed and angular correlation analyses have been performed. A comparison with Monte Carlo shell-model calculations pointed to a dominance of spherical states up to 1.5 MeV excitation energy, together with the appearance of two states of oblate character.

1. – Introduction

A microscopic description of the nuclear deformation is a central issue in nuclear physics, and shell-model calculations combined with extensive spectroscopic studies pursue this goal. Of high interest is the study of the shape-coexistence phenomenon, namely the presence of low-lying nuclear excited states associated to different shapes [1].

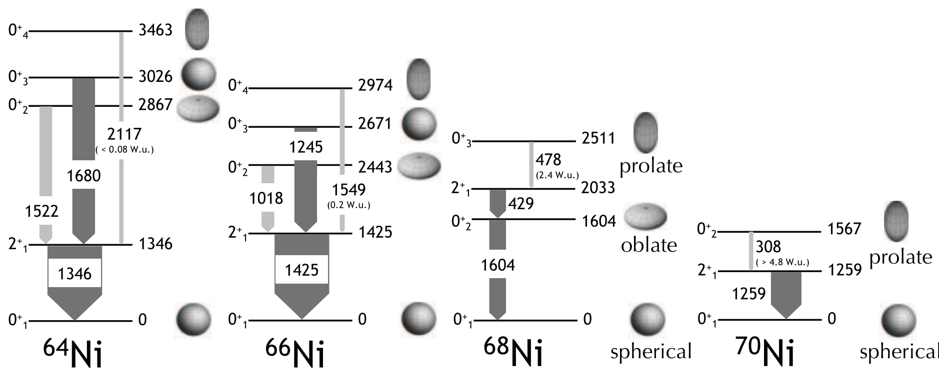

Fig. 1. – Partial decay schemes of Ni even-even isotopes with mass $A = 64$ to 70, focusing on the decay of the lowest 0^+ states [2,3]. The 0^+ states associated to spherical, oblate and prolate shapes, respectively, are indicated with a drawing of the nuclear shape.

Various theoretical calculations predicted the presence of shape-coexisting structures in the even-even isotopes of Ni [4-6], and experimental evidence confirmed the validity of these predictions for the even-even isotopes ^{64}Ni to ^{70}Ni [3, 7, 8]. Figure 1 shows a portion of decay schemes of these nuclei, with a focus on the lowest 0^+ states. The 0^+ states that have been associated to spherical, prolate or oblate shapes, respectively, are marked in the figure.

It is of high interest the investigation of even-odd nuclear systems as well, since they provide information to further test theory predictions. This work focused on the ^{65}Ni odd isotope, aiming at performing a complete low-spin spectrocopic study to be compared with Monte Carlo shell-model (MCSM) calculations [5]. Indeed, emergence of shape coexistence in this isotope is expected, since it lies between the even-even nuclei ^{64}Ni and ^{66}Ni, where spherical, prolate and oblate shapes have been observed [3, 7]. The ^{65}Ni nucleus was populated via neutron capture [9]. Such reaction permits to study the level scheme of a nucleus below its capture state and to access low-spin states, using γ-spectroscopy techniques [10-13]. The experimental details and results of the work are briefly described in the following section. The last section of this paper discusses the available experimental knowledge in comparison with MCSM calculations.

2. – Experiment and analysis

The experiment was performed at the reactor of the Institute Laue-Langevin in Grenoble, France. The ^{65}Ni nucleus was produced via a thermal neutron capture (n,γ) reaction on a ^{64}Ni target (86.7 mg) in powder form. The thermal neutron beam was delivered to the experimental site with a flux of 7.7×10^7 cm^{-2}s^{-1} [9].

The ^{65}Ni nucleus was populated in the capture state at 6098.28 keV of energy above the ground state, and its γ-ray decay was measured by the high-resolution FIssion Product Prompt gamma-ray Spectrometer (FIPPS) detector was used [14]. The FIPPS array was composed of 8 high-purity Ge clover detectors, symmetrically installed around the target position.

Thanks to the high resolution and efficiency of FIPPS, it was possible to perform a complete spectroscopic study of ^{65}Ni at low spin. Two new levels and 87 new γ-ray transitions were identified. Figure 2 shows the energy spectrum measured in coincidence

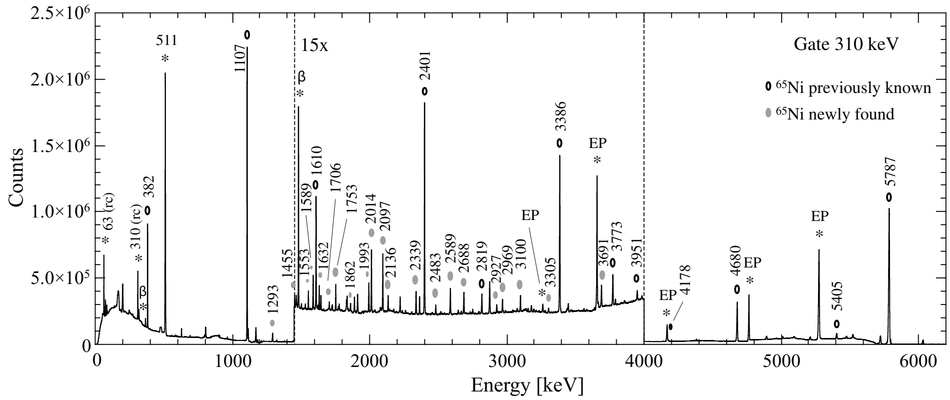

Fig. 2. – The coincidence energy spectrum obtained gating on the 310 keV ($3/2^-_1 \rightarrow 5/2^-_1$) transition is shown. Escape peaks (EP), radiation from β^- decay of ^{65}Ni (β) and random coincidences with ^{65}Ni itself (rc) are marked with a star.

with the most intense 310 keV transition from the second excited state to the ground state. Peaks corresponding to previously known (newly observed) transitions are indicated with open black ovals (full gray ovals) in the spectrum, respectively. A $\gamma\gamma$ angular correlation study was also performed. This led to the measurement of the multipolarity mixing ratio of 6 γ-ray transitions and the spin assignment for three excited states.

3. – Discussion and conclusions

The experimental level scheme of ^{65}Ni was compared up to 1.5 MeV of excitation energy with MCSM calculations [5], as can be seen on the left side of fig. 3. Such calculations were carried out using the pf-$g_{9/2}$-$d_{5/2}$ model space. As emerges from fig. 3, there

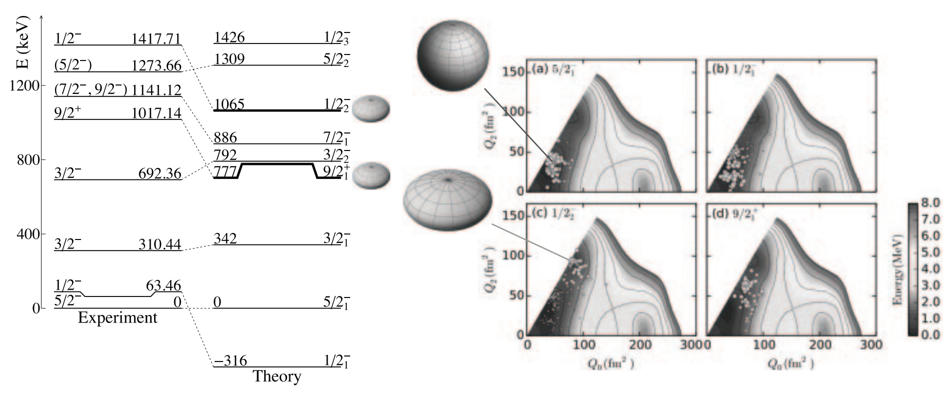

Fig. 3. – Left: comparison between the experimental results and the MCSM theoretical calculations for the excitation spectrum of ^{65}Ni, for excitation energies up to 1.5 MeV. The highlighted $9/2^+_1$ and $1/2^-_2$ excited states are associated to an oblate shape, according to a T-plot analysis. Right: T-plots obtained through MCSM calculations for four states of ^{65}Ni, indicated in each panel. The T-plots shown in panels (a) and (c) correspond to a spherical and oblate shape, respectively.

is a correspondence between experimental and theoretical states, despite a discrepancy in energy up to 400 keV. Moreover, an inversion between the ground state and the first excited state is observed.

The MCSM calculations provided also a description of the shape of the states under investigation through a T-plot representation (see right side of fig. 3). In this representation, circles on the potential-energy surface of ^{65}Ni indicate the projection of the MCSM eigenstates on the quadrupole moment coordinates (Q_0, Q_2). A cluster of circles, thus, indicates the dominance of a particular nuclear shape for a given state. For example, the T-plot in fig. 3(a) relative to the $5/2^-_1$ ground state indicates its spherical character, while the one shown in fig. 3(c) points to an oblate deformation for the $1/2^-_2$ excited state. According to this T-plot analysis, all the states below 1.5 MeV have a spherical structure, but the $9/2^+_1$ and $1/2^-_2$ states, where an oblate deformation emerges. Prolate deformations are predicted around 3 MeV, where comparison with experiment become more uncertain.

In conclusion, a spectroscopic study of ^{65}Ni via (n,γ) reaction has been performed, that permitted to extensively expand the previous knowledge of this odd system [9]. Through an angular correlation analysis, a number of mixing ratio values and spin assignments were established. The experimental level scheme was compared up to 1.5 MeV of excitation energy with MCSM calculations, that pointed to a dominance of spherical structures at low excitation energy, with the exception of two states ($9/2^+_1$ and $1/2^-_2$) presenting an oblate character. Further studies, employing the ^{13}C+^{64}Ni transfer reaction at sub-Coulomb energy, are ongoing in order to firmly locate the predicted prolate states at higher energies [15].

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