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LIFETIME MEASUREMENTS IN NEUTRON-RICH Fe AND Co ISOTOPES*

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Lifetimes of yrast states in neutron-rich Fe and Co isotopes were measured using the differential Recoil Distance Doppler Shift (RDDS) and the differential decay curves methods. The nuclei of interest were populated in multi-nucleon transfer in inverse kinematics. The deduced $B(E2)$ values are compared with large-scale shell-model calculations, leading to a better understanding of the mechanisms at the origin of the onset of collectivity in the region just below ^{68}Ni.

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1. Introduction

The region around ^{68}Ni has recently received considerable interest due to the observation of a significant subshell closure at $Z = 28$ and $N = 40$ [1,2]. Collective, single-particle and core-coupled states coexist in this mass region. Above $Z = 28$ in the odd-A, neutron-rich ^{69,71,73}Cu isotopes, a $5/2^-$ single-particle state, a $1/2^-$ collective state and a $7/2^-$ state interpreted as a $p_{3/2}$ proton coupled to the 2_1^+ level in Ni isotopes were identified [3]. The nature of these states was determined from excitation energies and $B(E2)$ values. Below $Z = 28$, in the Fe isotopes, the $N = 40$ gap presumably collapses, inducing a large deformation. This is revealed by the decrease in the excitation energy of the 2_1^+ levels and, more significantly, by the increase of their $B(E2)$ values. This rich variety of phenomena is also expected to occur in the Co isotopes, located between Ni and Fe. The $9/2_1^-$ state in the odd-mass Co nuclei was interpreted as a $f_{7/2}$ proton hole coupled to 2_1^+(Ni) isotone, and a $3/2_1^-$ state was identified at low excitation energy [4].

In this contribution we report on the first measurement of transition probabilities in neutron-rich even–even Fe and odd-mass Co isotopes between the first excited and the ground states. These states are interpreted in the shell model which allows us to draw some conclusions on the evolution of collectivity in this mass region.

2. Experimental results and theoretical calculations

The experiment was performed at the Grand Accélérateur National d'Ions Lourds (GANIL) using the differential RDDS technique [6], in combination with multi-nucleon transfer reactions in inverse kinematics. A ^{238}U beam at $6.5A$ MeV impinged on a 1.5 mg/cm^2 thick ^{64}Ni target. The target-like reaction products were detected and identified in the large-acceptance VAMOS spectrometer [7]. The optical axis of the spectrometer was positioned at 45° with respect to the beam axis, close to the grazing angle of the reaction. The focal-plane detection system of the spectrometer allowed the full reconstruction of the trajectories and an unambiguous identification of the reaction products in mass, charge and atomic number (see Fig. 1).

The RDDS technique is based on the use of a degrader located after the target at a distance compatible with the product of the recoil velocity and the expected lifetime of the states. The γ rays are emitted either before or after the degrader, hence when the emitting recoils have different velocities. The associated Doppler-shifted γ rays were measured with the EXOGAM array [8]. The data were collected for six target-degrader distances: 40, 120, 250, 350, 450 and 750 μm. The recoil velocity after the degrader was determined on an event-by-event basis using the VAMOS spectrometer.

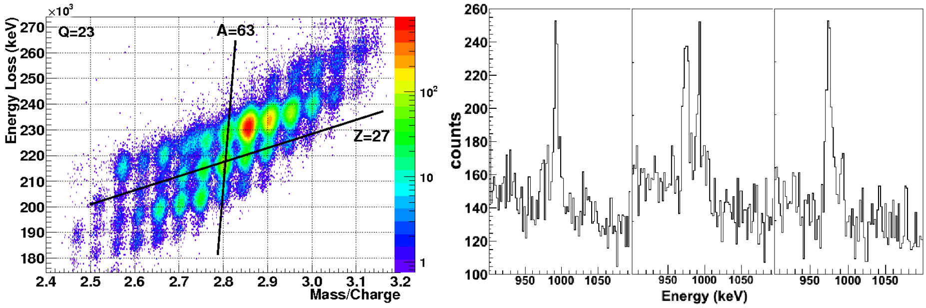

Fig. 1. Left: Typical identification plot of the VAMOS spectrometer showing the energy loss in the ionization chamber as a function of the mass-over-charge ratio, for a single charge state $Q = 23$. The straight lines highlight the peaks corresponding to the Co isotopes ($Z = 27$) and to mass $A = 63$. Right: Spectra showing the unshifted and shifted γ rays for the transition $3/2^-_1 \rightarrow 7/2^-_1$ in ^{63}Co for low (40 μm), central (350 μm) and high (750 μm) distances.

The lifetimes of the 2^+_1 states in ^{62,64}Fe were measured and the deduced $B(E2)$ values are $14.0(\pm 1.78)$ W.u. and $30.9(^{+13.8}_{-7.2})$ W.u., respectively. Shell-model calculations were performed in the fp, fpg and $fpgd$ valence spaces and are discussed in Ref. [5, 9]. The rapid onset of collectivity observed beyond $N = 36$ is remarkable and an analysis of the wave functions shows that it can be attributed to active neutron $g_{9/2}$ and $d_{5/2}$ orbitals at $N = 36$.

The lifetimes of the $3/2^-_1$ and $9/2^-_1$ levels in ^{63}Co were measured to be $15.4(\pm 1.8)$ ps and $0.9(\pm 0.5)$ ps. In ^{65}Co, only an upper limit of 17.3 ps could be established for the $9/2^-_1$ lifetime. These lifetimes translate into the following B(E2) values (assuming a pure E2 character for the $9/2^-_1$ decay): $3.62(\pm 0.45)$ W.u., $11.4(\pm 0.8)$ W.u. and > 0.65 W.u., respectively.

Fig. 2 presents the systematics in energy and $B(E2)$ values. The excitation energy of the $3/2^-_1$ level in Co and of the 2^+_1 level in Fe behave similarly, particularly when approaching $N = 40$. The same is true for the $9/2^-_1$ level compared to 2^+_1(Ni). These features seem to indicate that the states in Co can be explained in terms of a coupling to the 2^+_1 state in either Fe or Ni. This interpretation seems to be confirmed for the $9/2^-_1$ state in Co because of the $B(E2; 9/2^-_1 \rightarrow 7/2^-_1)$ value which is similar to $B(E2; 2^+_1 \rightarrow 0^+_1)$ in Ni (see Fig. 2). This is not so for the $3/2^-_1$ state. Even if the evolution of the $B(E2)$ values for Co and Fe with the neutron number N might seem remotely similar, their magnitudes differ by a factor of three.

Large-scale shell-model calculations in the fp and fpg valence spaces were carried out for Co isotopes (see Fig. 2). The interactions of Ref. [2] as well as the one of Refs. [10] overestimated $E2$ strength at $N = 36$. Also note that the fpg and fp calculations predict very different $B(E2)$ values

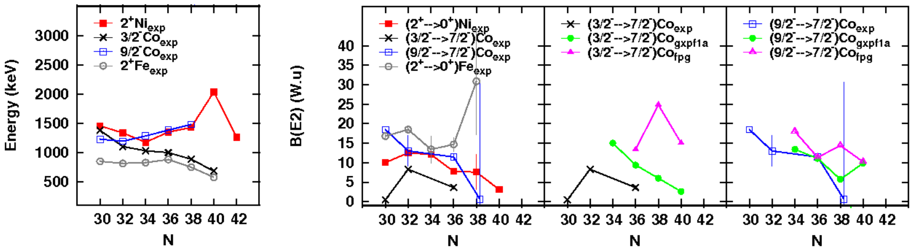

Fig. 2. Left: Excitation energy for the $3/2^-$ and $9/2^-$ states in the Co chain and for the 2^+ states in Fe and Ni isotopes as a function of neutron number. Comparison of the measured and calculated (in the fp and fpg valence spaces) $B(E2)$ values for the same states as a function of neutron number.

at $N = 38$, which makes ^{65}Co a good candidate to probe the evolution of the collectivity and hence the shell structure.

3. Conclusion and outlook

We have measured lifetimes of yrast states in ^{62,64}Fe [5] and ^{63,65}Co. The extracted reduced transition probabilities were compared with large-scale shell-model calculations. In Fe isotopes, the large increase in E2 strength indicates an onset of deformation and a collapse of the $N = 40$ gap. In Co isotopes, the $9/2^-_1$ state can be interpreted as a $f_{7/2}$ proton hole coupled to 2^+_1(Ni). The $3/2^-_1$ state has a more complicated character. Although it has a small $B(E2)$ value to the ground state, pointing toward a single particle nature, the shell model yields a very fragmented wave function which is more in line with a collective character. The measurement of $E2$ transitions in neutron-rich ^{65,67}Co would provide a sensitive probe of the evolution of the collectivity just below ^{68}Ni.

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