Medium-spin spectroscopy of the neutron-rich ^{84}Se isotope: decrease in energy of the N=50 neutron-core excitation

Etats de spin moyen du noyau riche en neutrons ^{84}Se : diminution en énergie des excitations au-delà du gap N=50

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Résumé *: Afin d'étendre notre connaissance des états de haut spin des isotones N=50 limitée jusqu'alors (pour les noyaux pairs-pairs) à ^{86}Kr, nous avons produit le noyau $^{84}Se_{50}$ par la réaction de fission induite par ions lourds ^{18}O+^{208}Pb à 85 MeV d'énergie de bombardement. Les états de moyen spin du noyau ^{84}Se ont pu être identifiés pour la première fois grâce au multidétecteur γ EUROBALL IV et le schéma de niveaux a été déterminé jusqu'à une énergie d'excitation de ~5 MeV et un moment angulaire de ~7ħ. Les résultats obtenus ont été interprétés par comparaison avec les schémas de niveaux à haut spin des isotones voisins. Nous avons pu mettre ainsi en évidence un affaiblissement du gap sphérique N=50 quand Z décroît de 38 à 34.*

Introduction

Study of nuclei close to ^{78}Ni is of primary importance to determine directly how the N=50 shell gap evolves at such large neutron excess. A very efficient method to estimate the energy of a shell gap is to study the particle-hole states in which one nucleon is promoted across the gap. For instance, the multiplet of six states with spin values ranging from 2^+ to 7^+ corresponds to the N=50 core-excitation ($\nu g_{9/2}^{-1} \otimes \nu d_{5/2}^{+1}$). These high-spin states have been measured in ^{90}Zr [1] and in ^{88}Sr [2] with transfer reactions and in ^{86}Kr using fusion-evaporation reaction with stable projectile [3]. The extension of such measurements to nuclei far from the stability valley can be done using another technique, fission induced by heavy ions.

We report here new results obtained in the ^{84}Se nucleus produced in the fusion-fission reaction ^{18}O+^{208}Pb at 85 MeV bombarding energy and studied with the EUROBALL IV array. Its medium-spin states have been identified up to spin 7ħ. From comparisons with the excited states known in the heavier N=50 isotones, three excited states with spin 5^+, 6^+ and 7^+ have been interpreted to be due to the neutron-core excitation [4].

I – Experimental procedures

The beam was provided by the VIVITRON accelerator of IReS (Strasbourg) and the target consisted of a self-supported 100 mg/cm^2 ^{208}Pb foil thick enough to stop the recoiling nuclei. The EUROBALL IV spectrometer was used to detect in coincidence the emitted γ-rays. A set of 4.10^9 three- and higher-fold events has been recorded and are available for subsequent analysis.

More than one hundred nuclei are produced at high spin in such experiments and the unambiguous identification of high-spin levels which are partially unknown is based on the fact that prompt γ-rays emitted by complementary fragments are detected in coincidence. This method has been used to identify the γ-ray cascades of the ^{84}Se nucleus. Its complementary fragments are the $^{136\text{-}139}$Ba isotopes, the total number of emitted neutrons being 6, 5, 4, and 3 respectively.

II – Experimental results

The first excited state in ^{84}Se is located at 1454 keV. In order to identify the second yrast transition of ^{84}Se, we have looked for new transitions in all the spectra gated by the most intense transition of the complementary fragments and by the 1454 keV ^{84}Se yrast transition. It appears that a 667 keV can be clearly assigned to ^{84}Se (cf. figure 1). The spectrum gated on these two yrast transitions reveals new transitions depopulating the high-spin states of ^{84}Se. They are given in the following table.

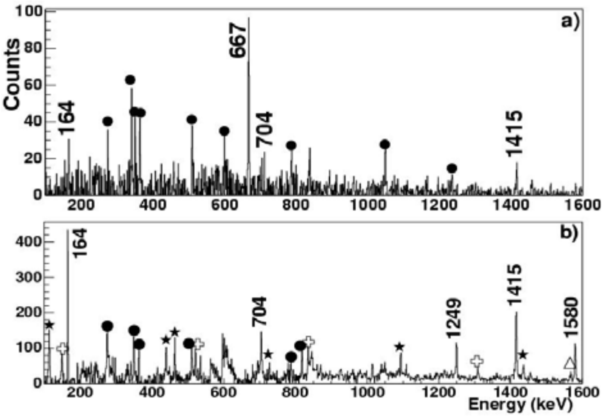

Figure 1: Double-gated spectra a) set on the 818 keV and 1454 keV yrast transitions of ^{136}Ba and ^{84}Se respectively and b) set on the 1454 keV and 667 keV yrast transitions of ^{84}Se. Transitions emitted by the complementary fragments, ^{136}Ba (circles), ^{137}Ba (triangles), ^{138}Ba (stars) and ^{139}Ba (crosses) are indicated in the spectra.

The level scheme presented in figure 2 has been deduced from further investigations of the coincidence data. It has been obtained up to 4.9 MeV excitation energy and spin I ~ 7ħ.

Spin values of the 1454 keV and 2121 keV states have been assigned from γ-ray angular correlation measurements in which the coincidence rate of two successive γ-transitions is analyzed as a function of the average relative angle between the two fired detectors. The statistics of our data set was unfortunately too poor to perform the same analysis for the other states of ^{84}Se.

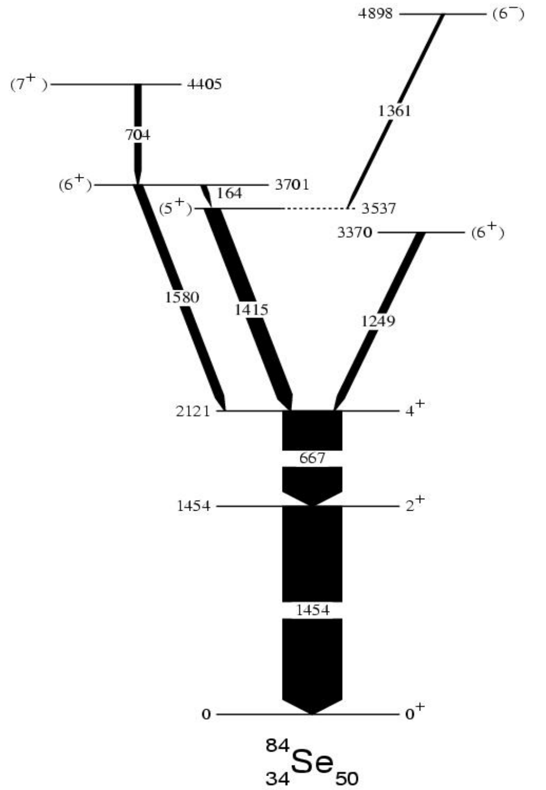

Figure 2: Level scheme of ^{84}Se obtained as fission fragment in the fusion reaction ^{18}O+^{208}Pb at 85 MeV beam energy.

II – Discussion

Shell-model calculations in large model spaces had been already performed in order to describe the structure of the N=50 and Z<50 nuclei [5,6,7]. However, they are unable to give reliable predictions for the lightest isotones, such as ^{84}Se.

The new results obtained in this work will be discussed taking advantage of the evolution of the experimental states in the neighbouring isotones and of results of shell-model calculations with large configuration spaces ($f_{5/2}$, $p_{3/2}$, $p_{1/2}$, $g_{9/2}$ orbitals for protons; $g_{9/2}$ and $d_{5/2}$ orbitals for neutrons allowing the neutron-core excitation) obtained for ^{86}Kr [3].

Medium-spin levels (I ≤ 8) of the four light N=50 isotones are presented in figure 3.

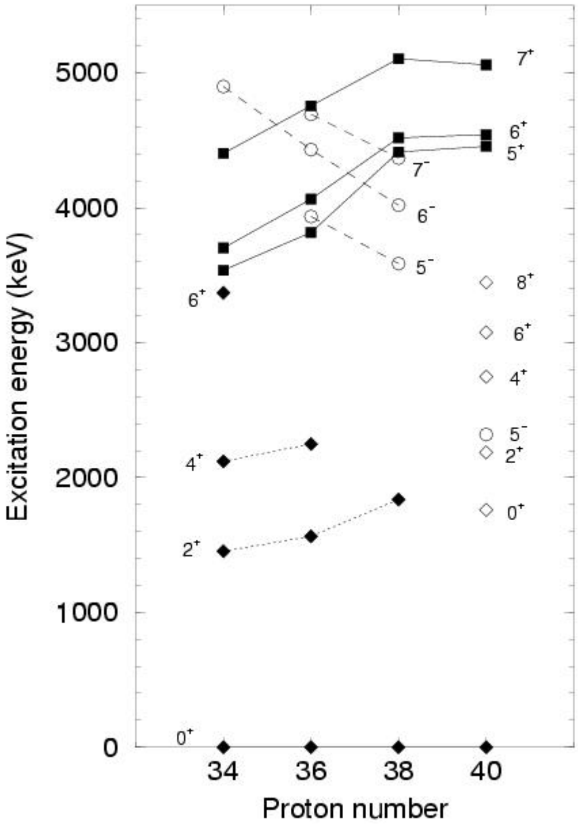

Figure 3: Evolution of the high-spin states of the four even-even N=50 isotones from Z = 34 (Se) to 40 (Zr). States with proton configurations within the fp shells are drawn with filled diamonds, those containing the $\pi g_{9/2}$ shell are drawn with empty symbols (diamonds and circles). States due to the neutron-core excitation, $\nu g_{9/2}{}^{-1} \nu d_{5/2}{}^{+1}$, are drawn with filled squares.

The configuration of the first excited states mainly involves the proton subshells, $f_{5/2}$, $p_{3/2}$, $p_{1/2}$. At higher excitation energy, the first negative-parity excited states have the main configuration, $\pi[p_{3/2}/f_{5/2}]^{-1}\pi g_{9/2}{}^{+1}$. States involving a neutron-core excitation will be discuss in more details. The configuration of the first neutron-core excitation, $\nu g_{9/2}{}^{-1}\nu d_{5/2}{}^{+1}$ gives a multiplet of states with spin values ranging from 2^+ to 7^+. The whole multiplets are known in the heavier N=50 isotones, ^{90}Zr and ^{88}Sr, thanks to transfer reactions. The results of shell model calculations for ^{86}Kr including or not a neutron valence space have clearly shown that its 5^+, 6^+, and 7^+ yrast states have to be interpreted in terms of the neutron-core N=50 excitation.

Similarly the three new states oberved in ^{84}Se at 3537, 3701, and 4405 keV, can be interpreted in terms of the $\nu g_{9/2}{}^{-1}$ $\nu d_{5/2}{}^{+1}$ neutron configuration, due to the N=50 neutron-core excitation.

The evolution of the energy of the 5^+, 6^+ and 7^+ states, drawn in figure 3, points out a lowering in their excitation energy (already visible from ^{88}Sr to ^{86}Kr) which goes on from ^{86}Kr to ^{84}Se. Therefore a weakening of the N=50 spherical gap takes place when Z is decreasing form 38 to 34.

Conclusion

High-spin structure of the N=50 nucleus have been populated using the fusion-fission reaction $^{18}O+^{208}Pb$ at 85 MeV and the transitions between the excited states of this nucleus have been measured with the EUROBALL IV spectrometer. The level scheme has been extended up to 4.9 MeV excitation energy and spin values of 7ħ. The interpretation of the results puts in light a weakening of the N=50 spherical shell gap, when Z decreases from 38 to 34.

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