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Letter of Intent to the INTC Commitee

Low-energy Coulomb excitation of ^{78,80,82}Ge with REX-ISOLDE and Miniball

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Introduction

We intend to measure the Coulomb excitation of the neutron-rich nuclei ^{78,80,82}Ge using the REX-ISOLDE facility and the Miniball array. The study of these nuclei will allow us to probe the predicted shell quenching of the N=50 shell [1] for medium-mass nuclei. In particular, the observed decrease in the energy of the 2^+ state when moving from Sr (Z=38) to Ge (Z=32) along the N=50 path was interpreted as being the signature of the reduction of the shell gap. This interpretation seemed to be also confirmed by the measured $B(E2)$ values in ^{88}Sr which are lower than those obtained in the lighter isotone, ^{86}Kr, suggesting an increased collectivity of the latter due to a weaker shell gap. The maximum collectivity and thus the weakest strength for the N=50 shell gap is expected in ^{82}Ge. Recently, B(E2) values in ^{78,80,82}Ge nuclei were measured at RIKEN by intermediate-energy Coulomb excitation [2]. Preliminary results of these measurements indicate values much lower than those expected from the systematics. In order to establish firmly the amount of collectivity in the ^{78,80,82}Ge nuclei which might bring additional empirical evidence for testing the predicted quenching of the N=50 shell closure, we propose the measurement of the $B(E2; 0^+ \rightarrow 2^+)$ values by Coulomb excitation using beams with energies around the Coulomb barrier. The study of these nuclei can be also regarded as the continuation of the project we started in 2002 at REX-ISOLDE aimed at the investigation of structure of the neutron-rich Zn and Ni nuclei [3, 4, 5].

Motivation

Neutron-rich nuclei in the vicinity of the doubly magic nucleus ^{78}Ni provide one of the best possibilities to investigate the evolution of the nuclear structure around the closed proton and neutron shells very far from stability. The large neutron-to-proton ratio in this region might allow the observation of unusual shell effects. For instance, the occurrence of a subshell closure at N=40 resulting in a doubly magic character for ^{68}Ni was predicted in the early 1980s [6, 7]. The restoration of this subshell gap ($\sim$3 MeV) separating the pf spherical shell from the $g_{9/2}$ intruder orbital was interpreted as being the consequence of the reduction of the spin-orbit surface interaction due to a weaker mean-field potential characteristic of the medium-mass neutron-rich nuclei [6, 7, 8]. However, this spherical subshell closure was found to be insufficiently large to stabilize the spherical shape when the residual interaction was taken into account [9].

Various theoretical models exist that come to different conclusions with respect to the quenching or not of the N=50 shell closure for the medium-mass neutron-rich nuclei. The reduction of the strength of the N=50 shell gap for nuclei with $Z \sim$32-38 was predicted by calculations using mass predictions from the infinite nuclear matter model [10]. A more recent HFB calculation [11], in which pairing is treated on the same footing as particle-hole interactions, also predicted a significant reduction of this shell gap. In such calculations the two neutron separation energy at N=50 drops from 18 MeV for $_{38}$Sr to 11 MeV for $_{32}$Ge and then below 8 MeV for $_{28}$Ni. HFB calculations based on Gogny's two-body effective interaction [12] and shell model calculations [13] predict on the other hand the persistence of the shell closure for the N=50 nuclei close to ^{78}Ni. Moreover, the experimental study of the medium- and high-spin states in the N=50, Rb, Br, Se and Ge nuclei, performed through the comparison with the shell model predictions assuming a closed N=50 core indicated a continued stability of the N=50 shell gap in the vicinity of ^{78}Ni [14]. The conclusions drawn in that work with respect to the constant size of the N=50 gap were, however, model dependent.

The rapid development in the last years of radioactive beam facilities is now able to offer the experimental information needed to solve the controversy about these predicted shell effects. Many experiments were proposed in order to investigate the magicity and strength of the N=40 subshell [3, 4, 5, 16] and N=50 shell gaps [14, 15] to clarify their nature.

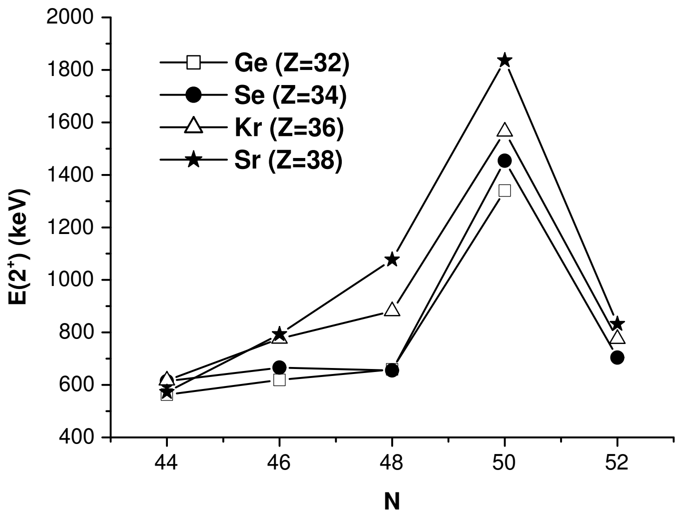

Figure 1: *E(2^+) systematics in the Ge-Se-Kr-Sr isotopic chains.*

The quenching of the $N = 50$ shell gap is supported by some empirical evidence found in the most experimentally accessible neutron-rich nuclei in this mass-region, namely those from $_{34}$Se to $_{38}$Sr. The comparison of the energies of the yrast states in the N=50 isotones revealed a systematic decrease of the energy of these states with decreasing the proton number and it was considered as a strong indication of a possible weakening of the N=50 shell gap when Z decreases from 38 to 34 [17]. In Figure 1, the evolution of the energies of the 2^+ states is presented as a function of neutron number for the different isotopic chains. The corresponding energies in the neutron-rich Ge nuclei are also included. The systematics show the $E(2^+)$ for the N=50 isotones decreases from $\sim$1.8 MeV in ^{88}Sr to $\sim$1.3 MeV in ^{82}Ge. The lighter Zn and Ni neutron-rich nuclei cannot be discussed in the present context due to the lack of experimental information about their structure.

Further empirical evidence supporting the decrease of the strength of the N=50 gap for Z approaching 32 comes from the inspection of the derivative of the two-neutron separation energy as a function of mass. The behavior of the derivative is reflected by the differential quantity $S_{2n}(A) - S_{2n}(A+2)$. The differential two-neutron separation energies of the Ge, Se, Kr and Sr nuclei are shown in Fig. 2.

The quenching of the N=50 shell closure should be also reflected in the behavior of the measured $B(E2; 0^+ \rightarrow 2^+)$ by an increase in collectivity when going from nuclei with Z=38 to nuclei with Z=32. At N=50, the $B(E2)$ of ^{88}Sr drops below those measured in the other isotones. Interesting to note, according to the experimental data presented in Fig. 3, ^{82}Se (Z=34, N=48) shows an increased collectivity with respect to the higher isotones, ^{84}Kr and ^{86}Sr. Thus, based on the $E(2^+)$ and ΔE_{2n} systematics, the $B(E2)$ values in the Ge nuclei are expected to be larger than those recently reported [2].

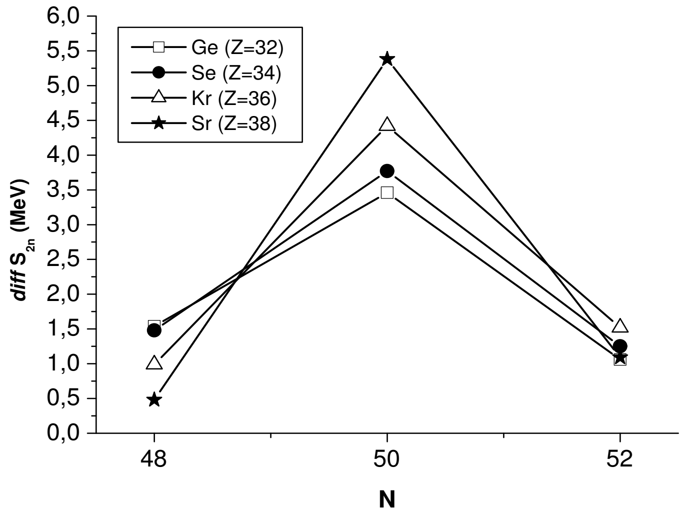

Figure 2: *Differential two-neutron separation energies in the N=50 isotones,* $S_{2n}(A) - S_{2n}(A+2)$*. The data are taken from the evaluation of Ref. [18].*

Since the Ge nuclei are very important in testing and understanding the quenching of the N=50 shell closure with decreasing proton number, we propose to remeasure the $B(E2)$ values in the neutron-rich ^{78,80,82}Ge in order to gain a precise knowledge about the size of this shell gap. A lower strength of the gap for the Ge nuclei with respect to Sr would result in an increased collectivity of the former. However, the effects on the $B(E2)$ values caused by the shell quenching are not expected to be significant, as shown by the measured values which were found to lie close to each other (see Fig. 3). It will not be easy to prove experimentally the N=50 shell quenching based on these quantities, therefore one need to employ those experimental techniques which can offer results with a high degree of accuracy and model independence. We might argue that the $B(E2)$ values in ^{78,80,82}Ge reported by the RIKEN group suffer from improper consideration of the nuclear interference effects and feeding from higher lying states characteristic to the Coulomb excitation experiments at intermediate energies. At REX-ISOLDE, these uncertainties are not present. A remeasurement of the $B(E2; 0^+ \rightarrow 2^+)$ in ^{78,80,82}Ge could be also

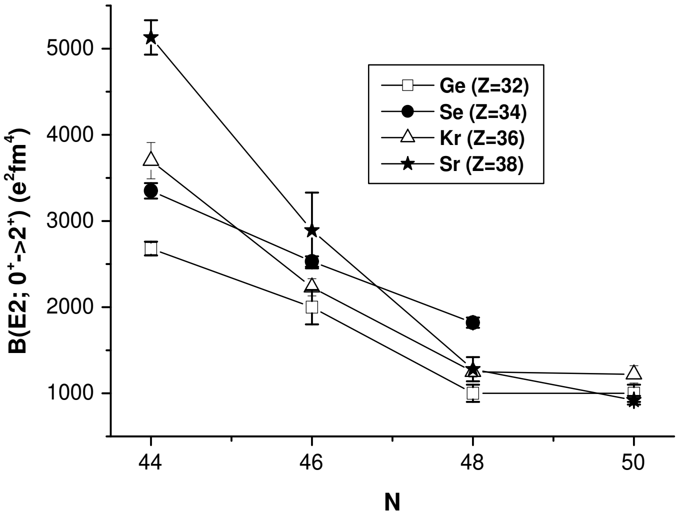

Figure 3: $B(E2)$ *systematics in the Ge-Se-Kr-Sr isotopic chains.*

regarded as a test for consistency of the results delivered by the two methods.

Experimental details

Radioactive Ge beams can be produced via proton-induced fission of ^{238}U by using an uranium carbide target in conjunction with RILIS. Unfortunately, this procedure gives rise to a very high Rb isobaric contamination. Preliminary investigations showed that even by using a proton-to-neutron convertor, the amount of Rb in the beam is still too high to make feasible any measurement of the heavier Ge isotopes.

Recently, the production of clean Ge beams at HRIBF and GSI-ISOL were reported, by making use of molecular beams, notably GeS$^+$ [19, 20]. The controlled formation of GeS$^+$ turned out to be surprisingly easy, using for instance, solid sulphur powder [20]. The ionization efficiency with a hot plasma ionization source for GeS$^+$ is expected to be at least as high as reachable with a good RILIS scheme and the release of the molecular GeS$^+$ beam much faster compared to the atomic Ge beam. Since the sulphur is not mono-isotopic (95% ^{32}S and 4.2% ^{34}S), the latter is expected to combine with the $A-2$ isotope of Germanium and give additional background. Such a problem might be solved by using an isotopically enriched ^{34}S (>99%). Using the cross-sections measured at GSI in inverse kinematics [21], the experimental yields are expected to vary from 10^9 atoms/μC for ^{78}Ge to several 10^7 atoms/μC for ^{84}Ge. Assuming a typical MK5 ionization efficiency of the order of 10% and about 50% of the Ge getting into the molecular sideband GeS$^+$, the expected yields after mass separations for $^{78-82}$Ge are resumed in Table 1. Furthermore,

	B(E2) $(e^2 fm^4)$	**E(2⁺)** (keV)	$\sigma_{0^+\to 2^+}$ $(barn)$	**Yields after mass separation** $(atoms/\mu C)$	**Events in photopeak** $(counts/hour)$
^{78}Ge→^{120}Sn	2000	619	1.352	$8{\cdot}10^7$	5300
^{80}Ge→^{120}Sn	1000	659	0.671	10^7	329
^{82}Ge→^{108}Pd	1000	1348	0.164	$4{\cdot}10^5$	2

Table 1: *Expected counting rates for the Coulomb excitation of ^{78,80,82}Ge. For the REX efficiency a value of 1% was considered. The integration of the calculated cross-section is made over the whole CD range (16.4°-53.3°).*

measurements performed last summer with a cocktail beam of ^{73}SeCO+^{69}GeS indicate an efficiency for the break-up of GeS$^+$ in the trap and Ge$^+$ extraction of at least 16% when the number of ions/bunch is relatively small (<10^7-10^8).

The γ rays following the Coulomb excitation of the projectiles and target nuclei will be detected with the Miniball array. For the detection of the coincident scattered particles the DSSSD-detector will be used. The experimental set-up will be similar to that used for the Zn and Ni runs [4, 5]. The high segmentation of the Ge and particle detectors will allow the Doppler correction of the γ-spectra.

Coulomb excitation of ^{78,80,82}Ge; expected count rates

The Coulomb cross-sections for projectile and target excitation were calculated using the code CLX [22]. The calculations were performed considering the current beam energy of REX of 2.87 MeV/u. As targets, we plan to use ^{120}Sn for the measurement of the Coulomb excitation of ^{78,80}Ge and ^{108}Pd for ^{82}Ge. Since we will perform a relative measurement of the $B(E2)$ values in the nuclei of interest, the ^{108}Pd in the latter case will be used in order to account for the low intensity of the ^{82}Ge beam. For both targets, the γ rays resulting from the target excitation are well separated from those following the projectile excitation. Considering a minimum surface separation of S=5 fm between the target and beam nuclei, the *safe distance* condition is fulfilled only for angles below 49° for ^{78,80}Ge and 43° for ^{82}Ge, therefore a limitation of the accepted angular range has to be made in the analysis. The $B(E2)$ values used in the calculations were those reported in ref. [2]. We assume a γ-ray detection efficiency of 5% at 1.3 MeV [23].

The number of expected events in the photopeak is summarized in Table 1 for a 2.3 mg/cm^2 ^{120}Sn target and a 2 mg/cm^2 ^{108}Pd target. In the calculations, an energy loss of 19.6 MeV/(mg/cm^2) and 21.3 MeV/(mg/cm^2), respectively, was considered. The expected high counting rate resulting from the elastically scattered ^{78}Ge nuclei could damage the CD detector, therefore the 3 inner strips of the detector might be covered during the experiment.

Project realization

In order to perform an accurate measurement of the $B(E2)$ values, one needs intense Ge beams of high purity. Preliminary investigations show that the best way for obtaining Ge beams is by using molecular beams. The results of these investigations are promising enough to initiate test experiments at REX-ISOLDE. Therefore we ask for 4 days for investigating, testing and optimizing the production of the Ge beams.

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