DECAY PROPERTIES OF ^{81}Ga AND ^{81}Ge AND OBSERVATION OF ABNORMAL ENERGY SHIFT IN THE $p_{1/2}$ STATE

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Abstract

^{81}Ga is efficiently produced in the isotope separator on-line facility OSIRIS at Studsvik, utilizing thermal fission of ^{235}U. The fission products are extracted from a combined target/ion-source system and mass-separated. Gallium is one of the most favourable elements for this ion-source. The germanium isobars are studied as daughter products.

Investigations involving singles γ-ray spectroscopy, γγ-coincidences, βγ-coincidences and level half-life measurements have been performed. Detailed decay schemes for ^{81}Ga ($T_{1/2}$ = 1.23 s) and the two isomers of ^{81}Ge (both with $T_{1/2}$ = 7.6 s) are presented. The lowest lying states in ^{81}Ge are interpreted within the framework of the collective model. Positive parity intruder states are observed and characterized. A shift of about 500 keV in the relative energy of the $p_{1/2}$ state is observed, resulting in a 1/2+ β-decaying isomeric state in ^{81}Ge. In the decay of the high-spin isomer of ^{81}Ge, selective population of a small number of states is observed.

On the basis of the level schemes and the βγ-coincidence measurements, total β-decay energies of both nuclides have been deduced.

1. Introduction

Although they are expected to possess interesting structural phenomena, the neutron-rich nuclei slightly below the closed neutron shell N=50 have not been subject to extensive investigations, mainly due to difficulties in obtaining source strengths sufficient for experimental studies. In this paper, we present experimental results obtained for the decay of ^{81}Ga and ^{81}Ge, as part of a more extensive survey of the nuclear properties in this region[1,2].

From recent studies of other nuclei in the same region, mainly of selenium isotopes [3,4], the presence of positive parity intruder states at relatively low energy has been clearly demonstrated. Although these states are not strongly populated via β-decay, neither directly nor indirectly[4], it is of interest to look for them also in germanium nuclei, whose structure are expected to be quite similar to the structure of isotonic selenium nuclei.

Additionally, there has been some ambiguity concerning the decay of ^{81}Ge. In other even Z, odd N nuclei in this region, two β-decaying isomers are always present, arising from the close-lying configurations $p_{1/2}$ and $g_{9/2}$. The half-lives of these isomers are normally considerably different. However, preliminary investigations at this laboratory[5] have revealed that all γ-rays arising from the decay of ^{81}Ge have similar half-lives.

2. Experimental techniques

The experiments were performed at the OSIRIS mass-separator at the R2-0 reactor at Studsvik. The separated isotopes were collected on an aluminium coated plastic tape which was used to transport the sources. At mass-number 81, the sources produced are almost exclusively gallium. These favourable conditions are achieved because the efficiency of the target/ion-source system at OSIRIS[6] is very low for the daughter products germanium, arsenic and selenium. The conditions for a detailed study of the decay of neutron-rich gallium isotopes and their germanium daughters are thus good.

Measurements of γ-rays and conversion coefficients were performed by means of two coaxial 80 cm^3 Ge(Li) detectors. We also used an X-ray detector to look for γ-rays down to 15 keV, but no transitions below 93 keV were observed at the mass number 81. Simultaneously, the conversion electrons were measured by means of a Si(Li) detector. The measurements of γγ-coincidences were performed in 180° geometry. Single γ-ray spectra were detected with different collection- and counting periods, in order to ensure the isotopic assignment of the transitions. Additionally, multispectrum analysis was performed in order to look for isomers, in particular in ^{81}Ge.

Tables containing the γ-ray energies and intensities, as well as the coincidence relations, have been published separately[7] and may be obtained from the laboratory at request.

The measurements of the βγ-coincidences used for the deduction of total decay energies were performed by means of a Si(Li) detector in coincidence with two multiplexed 80 cm^3 Ge(Li) detectors. The details of the experimental procedure for these measurements are given in ref.[8].

The measurements of level half-lives were performed with a method similar to the one applied by McDonald et al. in previous measurements at this laboratory[9]. The results of their preliminary measurements were confirmed, and a value for the half-life of the second excited state in ^{81}Ge was obtained.

3. Results

On the basis of the measurements described above, we have obtained a detailed decay scheme for ^{81}Ga and ^{81}Ge, as well as values for their total decay energies, Q_β.

3.1 The ^{81}Ga decay

The decay scheme for ^{81}Ga is shown in Fig. 1. As expected from systematics an isomeric state at 679 keV, was observed in ^{81}Ge. This isomer seems to decay entirely by β-emission, the γ-ray branching was estimated to be less than 1 %. From the multispectrum analysis of the γ-spectra, it was found that both isomers possess the same half-life, 7.6 ± 0.6 s.

Although it is impossible to investigate the states in ^{81}Ge by means of nuclear reactions, most of the levels below 1.5 MeV are relatively easily interpreted by means of level systematics and

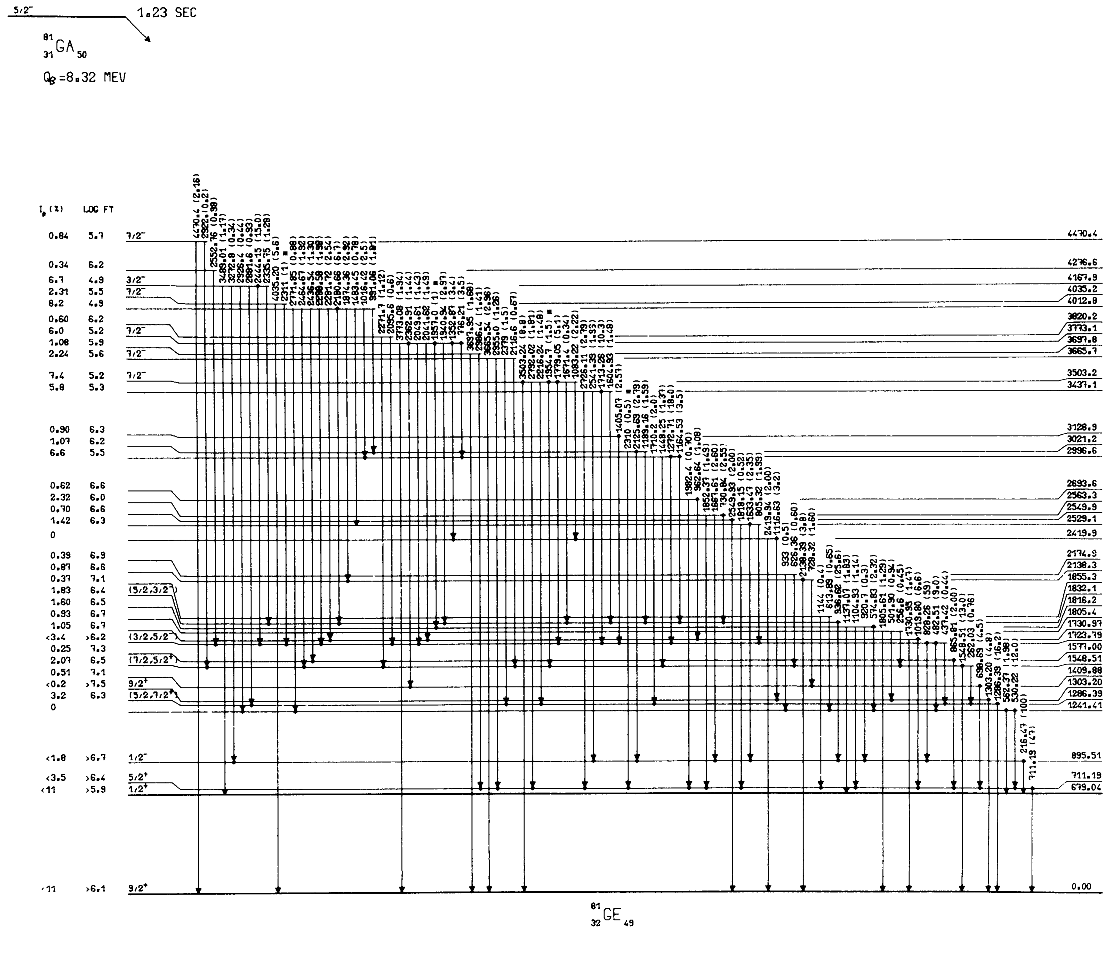

Fig. 1 The decay scheme for ^{81}Ga

simple physical arguments. A level systematics for odd-mass N=49 isotones is shown in Fig. 2. As seen from Fig. 2 the isomeric state is $1/2^-$ in all other odd-mass N=49 nuclei. However, in ^{81}Ge, the isomeric state at 679 keV is probably $1/2^+$, while the 895 keV state is likely to be the $1/2^-$ state. The 216 keV transition between the two levels has multipolarity E1 with 92 % confidence[1]. Thus, the two levels probably have different parity. For several reasons, the $1/2^+$ assignment is preferred for the isomeric state; Firstly, there is no 679 keV γ-transition observed, as one should expect from systematics. Secondly, the characteristic phonon states are observed in all other odd-N nuclei in this region. These are stongly populated indirectly in β-decay and deexcite to the $1/2^-$ state. Such states are also observed in ^{81}Ge, and they deexcite mainly to the 896 keV level. The 679 keV state is weakly indirectly populated, except for the 216 keV transition, in analogy with other $1/2^+$ intruder states. Additionally, its decay mode also indicates a different character (see next section).

The half-life of the 711 keV state was measured to 3.9±0.2 ns. If the multipolarity is assumed to be purely E2, this implies a hindrance factor F_W = 26.6±1.4. The half-life of the 583 keV state in the isotonic nucleus ^{83}Se, which is known to be the $5/2^+$ intruder state[3], has been recently measured[10] by means of the reaction ^{82}Se(d,p)^{83}Se to be about 5.5 ns, corresponding to a hindrance factor $F_W \approx 14$. From the similarity between the hindrance factors, as well as the decay properties of the states and expectations from level systematics, it is likely that the 711 keV state is the $5/2^+$ intruder state.

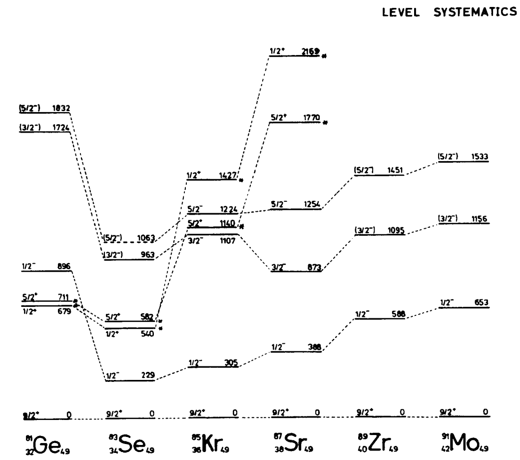

Fig. 2 Level systematics for odd mass N=49 isotones.

3.2 The ^{81}Ge decay

Although there are two β-decaying isomers in ^{81}Ge, we only observe one half-life. It is thus necessary to make the isomeric assignments by means of physical arguments.

The decay of the two isomers of ^{81}Ge is shown in Fig. 3. Due to the similarity in half-life, the schemes must be considered tentative, but by making use of the large differences between the spins and comparing with the well-known decay of the isotonic nucleus ^{83}Br, where there is a considerable difference between the half-lives of the isomers, it is possible to assign most transitions to a specific isomer. This problem is discussed in more detail in ref.[1].

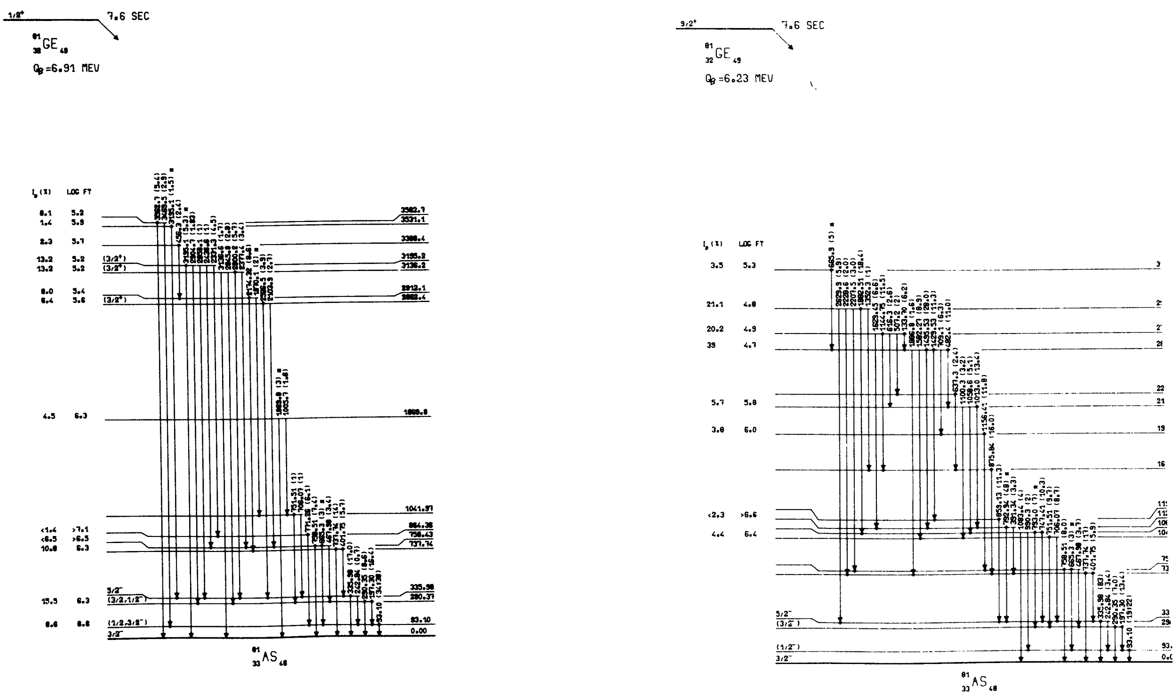

Fig. 3 The decay of the two isomers of ^{81}Ge

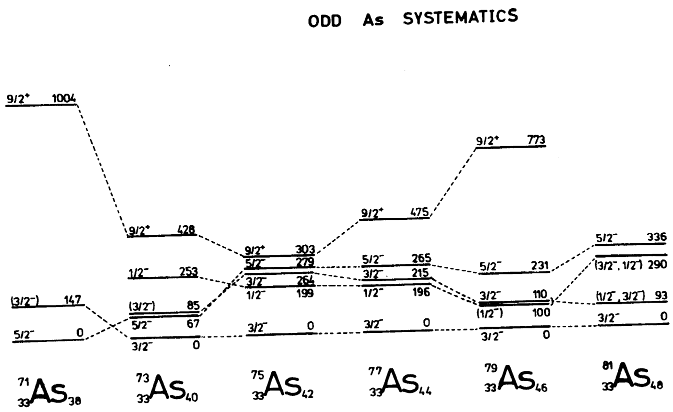

Fig. 4 Level systematics for odd mass As-isotopes

A systematics of levels in odd-mass As-isotopes is shown in Fig. 4. The decay properties of ^{81}As show[4] that the ground state is $3/2^-$. The 336 keV level is given the assignment $5/2^-$, from systematics as well as the strong indirect population from the decay of the $9/2^+$ isomer of ^{81}Ge. The states at 93 and 290 keV are either $1/2^-$ or $3/2^-$, but no firm assignment is possible. From systematics, the $3/2^-$ assignment is most likely for the 290 keV state.

The most characteristic feature of the ^{81}Ge decay is the strong population of a few levels at about 2.6 MeV in the decay of the $9/2^+$ isomer. This is probably due to the β-transition $g_{9/2} - \to \pi g_{7/2}$, which is expected to occur at about this energy. The total reduced β-transition probability of the three strongly populated states is characteristic for this type of transition.

It is also notewhorthy, that the 93 and 290 keV states are populated about equally strongly in the decay of the low-spin isomer. In all other odd-mass As-nuclei, the low-lying $1/2^-$ state is very weakly populated in the decay of the low-spin isomers of Ge-nuclei. This is an additional argument for the $1/2^+$ assignment of the isomeric state in ^{81}Ge.

3.3 The measurements of total decay energies

In the decay of ^{81}Ga 50 % of the β-particles feed levels between 3.0 and 4.5 MeV. Transitions depopulating the levels 2997, 3437, 3503, 4013, 4035, 4168, and 4470 keV were chosen for the experiment. The mean value of the determination is

$$^{81}\text{Ga: } Q_\beta = 8.32 \pm 0.15 \text{ MeV}$$

For our investigation of both the isomers of ^{81}Ge, we chose rather "strong" β-transitions depopulating the high lying levels between 2.86 and 3.56 MeV and 2.62 and 3.29 MeV respectively. As weighted mean we get the following Q_β-values:

$$^{81g}\text{Ge: } 6.22 \pm 0.13 \text{ MeV}$$

$$^{81m}\text{Ge: } 6.93 \pm 0.28 \text{ MeV}$$

The difference between the isomeric state is thus found to be 0.7±0.3 MeV which confirms the assumption in section 3.1 that the isomeric state lies 679 keV above the ground state in ^{81}Ge.

The details of the determinations of the total β-decay energies of ^{81}Ga and ^{81g,m}Ge are given in ref.[8].

4. Discussion

4.1 The structure of ^{81}Ge

Two types of positive parity states occur at low energy in ^{81}Ge, i.e. hole + phonon states at about 1.3 - 1.5 MeV and a pair of intruder states at about 0.7 MeV. Several other states observed below 2 MeV are probably also intruder states. A number of relatively low-lying $3/2^+$ states may be expected, but a firm spin assignment is not possible.

The most extensive theoretical investigation of odd-mass N=49 nuclei has been performed by Heller and Friedman[11] who calculated theoretical energy spectra using a Coriolis coupling model with pairing included. Using different values for the deformation parameter, they calculated spectra for ^{85}Kr and found that with $\beta \approx 0.2$, a pair of $1/2^+$, $5/2^+$ intruder states occur at about 600 keV, in fair agreement with the experimental findings for ^{83}Se[3] and ^{81}Ge.

For the odd-mass indium nuclei (Z=49), a greater amount of experimental material is available, as well as the amount of theoretical treatments.

In a rotational description[12-14], the positive parity intruder states are interpreted as members of the $1/2^+$ 431 rotational band, which is predicted to occur at low energies even at a relatively moderate deformation. In this model a fair reproduction of the position of the intruder states was obtained, but unrealistic values for the decoupling parameter had to be applied to reproduce the sequence of the levels.

A different and more successful approach has been used by Heyde et al.[15-17] who performed unified model calculations of the odd-mass indium isotopes, taking into account single-hole as well as single particle/two-hole configurations. With this model they obtained a satisfactory reproduction of the energy spectra for a large number of the odd-mass indium nuclei. Calculations for N=49 have not yet been performed.

A number of $7/2^-$ states observed at about 3 MeV in ^{81}Ge are strongly populated in β-decay, and are believed to be states with a strong $f_{7/2}$, neutron-hole character, arising from the transition $f_{7/2} \rightarrow f_{7/2}$, which are expected at about this energy.

4.2 <u>The structure of ^{81}As</u>

In an approach analogous to the one applied for N=49 nuclei, Scholtz and Malik[18] have performed calculations of spectra for a number of odd-proton nuclei in the region slightly below the N=50 neutron shell, but the agreement with experiments is not as satisfactory as for the similar calculations in ref.[11]. In particular, the energy of the first excited $3/2^-$ state is overestimated. The model has more success in predicting the position of the first positive parity states in this type of nuclei. A pair of states with spin $9/2^+$ and $5/2^+$ is predicted at relatively low energy. In ^{81}As, however, the conditions do not allow an experimental identification of these states.

The decay of the $9/2^+$ isomer in ^{81}Ge is characterized by a pronounced selectivity, populating only 3-4 states in ^{81}As strongly. These states are believed to have a strong single-neutron character, arising from the transition $g_{9/2} \rightarrow g_{7/2}$.

Acknowledgements

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