Decay properties and Q_β value of ^{82}As

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The β decays of the two ^{82}As isomers have been investigated by β- and γ-ray spectroscopy to elucidate details in the population of levels in ^{82}Se, and to determine the ground state energy of ^{82}As. The relative positions of the β-decaying states have been determined for the first time. The spin of the ground state, previously assumed to be 1^+, is proposed to be 2^-, in agreement with systematics. The new data confirm many previously known features of the ^{82}Se level scheme, but has also led to significant corrections. During the course of this work, the first information on absolute γ-ray intensities in the decay of ^{82}Ge was obtained.

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The decay of ^{82}As has been investigated several times in the past [2,1,3], but important data on details of the decay are still missing. It is known that there are two isomers in ^{82}As, but the relative positions of these two levels have so far not been determined. The two levels have been assigned either as a 1^+ state and a 5^- state [2], or as 2^- and 5^- [3] in previous works. There was a need for additional data on the β-decay properties in order to choose between these alternatives.

Being close to stability, the position of the ^{82}As ground state is of substantial interest in order to correctly place the more exotic isobars on the scale of excitation energy. Using precise Q_β measurements to determine the mass differences, the positions of both the ^{82}As levels can be obtained. Such experiments rely heavily on the level scheme of the daughter nuclide. However, early results from the current work indicated that the existing level scheme of ^{82}Se [4] is not entirely correct. The tentative placements of several γ transitions, in a previous study [2], did not give consistent results when used in the analysis of the $\beta\gamma$ coincidence data set intended for the Q_β determinations. Therefore we also included a γ-ray spectroscopy study of the ^{82}As decay in the present work. The work reported here is part of a larger effort to determine Q_β values and neutron separation energies in the vicinity of the $N=50$ closed shell. The new data obtained for the ^{82}As decay and the structure of ^{82}Se provides a solid basis for this larger effort.

The experiments were done at the OSIRIS facility at Studsvik, Sweden, using $\beta\gamma$ and $\gamma\gamma$ coincidences and γ-ray multi-spectrum scaling (MSS). The γ-ray spectroscopy was performed using standard coaxial HPGe detectors, while a Low Energy Photon Ge detector (LEP) was used as a β detector. This LEP detector had been extensively calibrated to permit its use as a spectrometer for electrons. The detector response to mono-energetic electrons was studied over the range 1–8 MeV using the BILL spectrometer [5] previously in use at Institue Laue-Langevin, Grenoble, for energy selection of conversion electron lines following thermal neutron capture. The BILL spectrometer was used also to determine the energy losses in the windows of 0.25 mm Be and 0.08 mm Al, which separate the LEP from the mass-separator vacuum. The uncertainties in the derived β spectra end points due to an incomplete knowledge of the detector response are estimated to a few keV for 2 MeV transitions and about 30 keV for transitions of 9–10 MeV. The energy scale is calibrated on-line using known γ-ray energies in the activity being studied together with a source emitting the 6129 keV line from ^{16}O. Additional descriptions of the spectrometer and the methods employed are found in Refs. [6,7].

The neutron induced fission products from the ^{235}U target were ionized by plasma ionization, and the mass separated $A=82$ beam was collected in front of the detector system on a movable mylar tape. Tape movements were used in order to minimize contributions from possible contaminations by long lived nuclides. In the MSS experiment, tape movements were followed by a measurement cycle comprising one time group of beam collection, followed by seven groups of data taken with the beam deflected. The group time was chosen to 10 s, which gave good conditions for study of the decays of ^{82}Ge, ^{82g}As and ^{82m}As, having half-lives of 4.6, 19.1 and 13.6 s, respectively. An example of the MSS data is given in Fig. 1, while Fig. 2 shows an example of the $\gamma\gamma$ coincidence data.

The $\beta\gamma$ coincidence measurements were performed using a low counting rate of less than about 2 kHz in the β-detector, in order to reduce possible effects due to pulse pile-up. For the same reason, a gated integrator amplifier

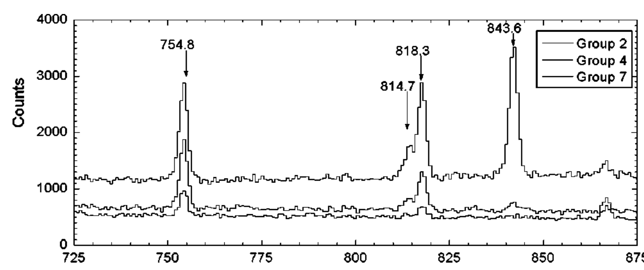

FIG. 1. Example of the MSS data. The differences in the time dependence for the three decays are visible. The 843.6 keV transition belongs to the ^{82}Ge decay, the 754.8 keV transition to the ^{82g}As decay, and the 814.7 and 818.3 keV transitions are due to the ^{82m}As decay. The spectra are shown in the order listed in the inset, with Group 2 as the topmost spectrum.

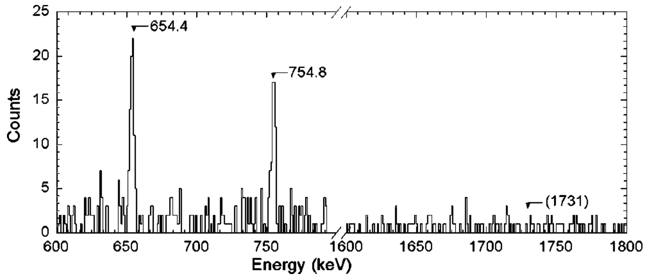

FIG. 2. Example of the $\gamma\gamma$ coincidence data, showing the (background subtracted) γ-ray spectrum obtained by gating on the 2835 keV transition. The data show that this transition is coincident with the 655 and 755 keV transitions and is not coincident with the 1731 keV transition, as previously proposed [1,2].

with a short time constant of 1 μs was used, as well as active pile-up rejection electronics.

In the current work, we could take advantage of re-examination of a data set obtained by Galy *et al.* [8] in a study of the fission product yield distribution. This data set included results from time sequential simultaneous measurements of both γ rays and β particles, and could be used to derive the absolute intensities of some γ transitions. The intensity of the 754.8 keV transition of the low spin ^{82}As isomer was found to be $6\pm3\%$/decay using the data of [8]. This limits the β feeding of the ground state to 50% or less. In the calculation of β-feeding and log ft-values, the β feeding to the ground state was taken to be $25\pm25\%$/decay. We also found the absolute intensity of the 1091 keV transition in the decay of ^{82}Ge to be $80\pm20\%$/decay.

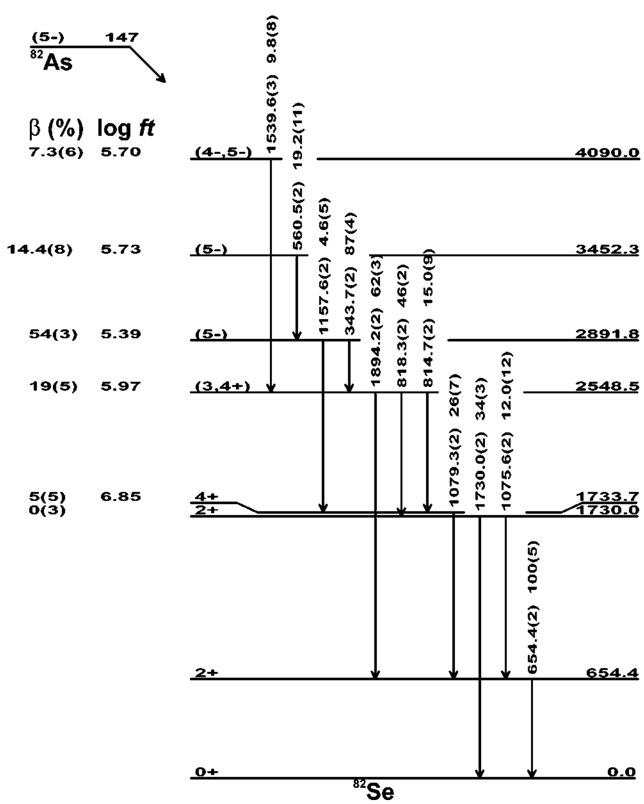

FIG. 3. Levels of ^{82}Se populated in the decay of the 5^- isomer of ^{82}As. For absolute γ intensities in %, multiply by 0.75.

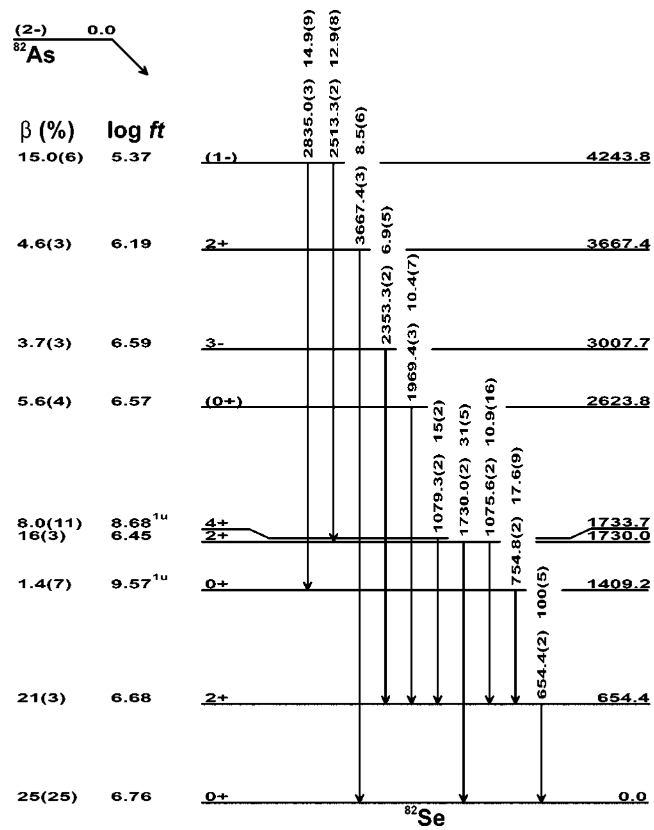

FIG. 4. Levels of ^{82}Se populated in the decay of the 2^- ground state of As. The large uncertainty of the β-feeding to the ground state is discussed in the text. For absolute γ intensities in %, multiply by 0.54.

All γ-ray transitions found to follow the decays of the ^{82}As isomers could be placed in the decay schemes by use of the $\gamma\gamma$ coincidence data. The results of the γ-ray spectroscopy study are therefore given in the decay schemes only, with no separate tabulation of γ-ray properties. One should note that the transition energies determined presently differ significantly from those of the compiler [4]. The energy scale used by us was established by standard calibration sources and confirmed by the presence of lines from ^{24}Na (from the room background) in our spectra.

The level scheme constructed from the data on the decay of the (5^-) isomer of ^{82}As, see Fig. 3, is essentially identical to the existing level scheme [4], while the level scheme for the decay of the low spin isomer shown in Fig. 4, differs from Ref. [4] in important respects. The two states at 2623.8 and 3007.7 keV, previously observed in reaction spectroscopy only, were now found to be well populated also in the β decay. The two highest lying of the tentatively proposed [4] states could not be confirmed by us. Figure 2 shows the coincidence spectrum seen when gating on the 2835 keV transition, giving no evidence of the previously assumed [1,2] coincidence with a 1731 keV transition. The strong 2835 keV transition was now found to depopulate a new state at 4244 keV, with a probable assignment of 1^-. Most of the other levels observed have spins well established from reaction experiments.

Some lower lying levels of ^{82}Se are populated in the de-

TABLE I. Total β decay energies of the ^{82}As isomers. All energy values are in keV.

Isomer J^{π}	Gating γ ray energy	Final state energy	End point energy	Q_{β} value
2^-	755	1409	6137(163)	7546(163)
	2513	4244	3269(38)	7513(38)
	2835	4244	3295(26)	7539(26)
			Average	7531(21)
5^-	1540	4090	3566(35)	7656(35)
	560	3452	4231(19)	7683(19)
			Average	7677(17)

cays of both As isomers. The MSS data give a possibility to separate these two contributions to the intensities of γ-ray transitions showing composite decay curves, and thus to deduce the direct β feeding of the lower lying states. In the case of the 4^+ level at 1733.7 keV, we found no strong direct β feeding from the (5^-) isomer, but observe a substantial feeding from the lower spin isomer, which strongly favours an assignment of (2^-) for this latter state. The 1^+ assignment proposed by Kratz *et al.* [2] is not compatible with a direct feeding of the Se 4^+ level. Assignments of (2^-) and (5^-) for the ^{82}As states agree with all of our observations and are adopted in the following. The (2^-) assignment for the ground state is plausible also in the view of our observation (see above) regarding the ^{82}Ge decay.

The analysis of the end point energies of the β spectra projected from the $\beta\gamma$ coincidence data set is strongly dependent on the choice of the gating γ-ray transitions. Good candidate γ rays for gating should depopulate levels with little feeding by γ transitions from higher lying states. Such feeding can add unwanted components to the β spectrum. The gating transition should also be free from coincidences with γ rays causing photo peak events in the region near the end point energy of the projected β spectrum. The decay of the (2^-) isomer gives a good opportunity for projecting clean β spectra by gates on the 2513 and 2835 keV transitions. In the decay of the (5^-) isomer, similarly clean gates were obtained using the 560 and 1541 keV transitions in the Q_{β} determination. The analysis of end point energies was performed by fitting a simulated pulse height distribution to the experimental data. This simulated distribution was generated by applying the known detector response function to a calculated spectrum, having a shape according to the Fermi theory. The results of the analysis are given in Table I. Examples of fits to the data are shown in Fig. 5.

Using the revised level schemes, a Q_{β} value of 7531 ± 21 keV was obtained for the (2^-) state of ^{82}As. This result supersedes a preliminary value obtained before the decay scheme revision, and quoted by Wapstra *et al.* [9]. As expected from the systematics of the heavier isotones ^{84}Br and ^{86}Rb, the (2^-) isomer is the ground state of ^{82}As, while

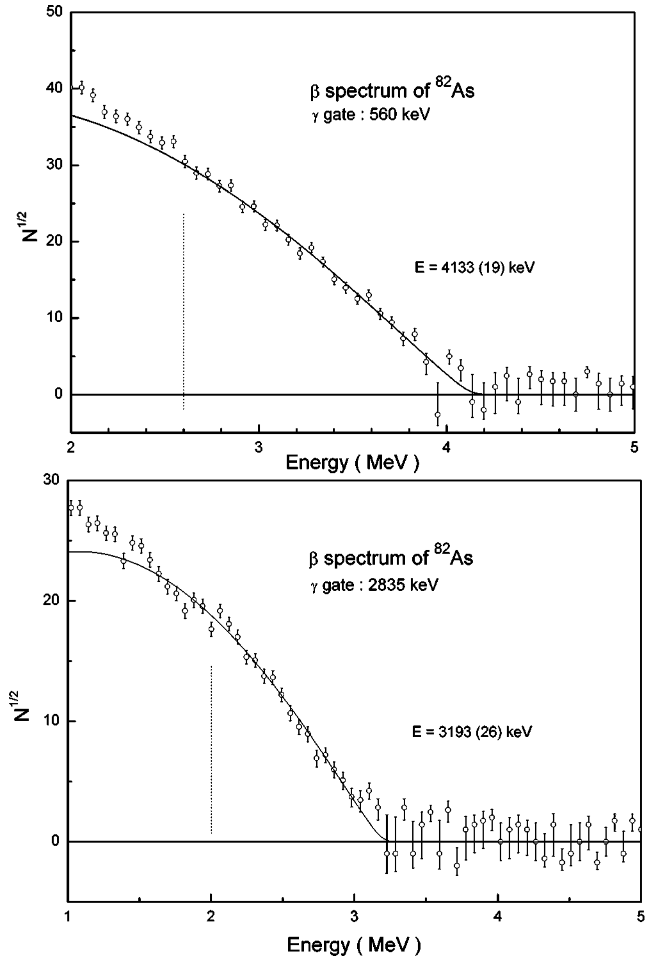

FIG. 5. Examples of the determination of β-spectra end points from the $\beta\gamma$-coincidence data. The vertical axis was selected as the square root of the pulse height distribution in order to better show the quality of the fits (solid curves). The asymmetrical error bars at low counts are simply a consequence of this choice of vertical scale. Note that the end point energies shown have not been corrected for the energy losses in the vacuum window.

the (5^-) state is located at 146 ± 27 keV. Had the old level scheme [4] of ^{82}Se been used in the analysis, the (5^-) state would have been suggested as the ground state. This serves as an illustration of the importance of having correct level schemes when deriving total decay energies.

The ^{82}As ground state can be described as a coupling of the $\nu^{-1}g_{9/2}$ neutron hole in antiparallel to the odd proton in the $\pi f_{5/2}$ orbital. The (5^-) isomer can be a member of the same multiplet, or also have a contribution from acoupling involving $\pi p_{3/2}$. In either case, an isomeric M3 transition would be of allowed type. This expected isomeric M3 transition was searched for in the MSS data, resulting in an upper intensity limit of about 2–3%/decay of the (5^-) state. The partial half life for the γ decay is thus of the order of 5×10^2 s, or greater, which is reasonable for a M3 transition in this energy range.

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