Measurement of the Q_β value for the β decay of mass separated $^{84}As \to ^{84}Se$

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The Q_β value for the β decay of ^{84}As $\to ^{84}$Se has been measured for the first time. The value of 7195±200 keV is in disagreement with the value of 9780 keV derived from systematics. However, it is in agreement with results inferred from sums of average β and γ decay energies reported for decay heat measurements.

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The determination of accurate β-decay information is important as input to theoretical mass calculations, which are essential components to a better understanding of nuclear structure and astrophysical processes. The β-decay end-point energy (Q_β value), along with the average β and γ energies are also crucial in decay heat calculations for reactor and spent fuel storage technologies. The isotope separator group, OSIRIS, at Studsvik [1] has been especially active in the latter endeavor. In a recent compilation, Rudstam *et al.* [2] listed the results of their measurements of the β and γ spectra of short-lived fission products. As a consistency check on their results, they use the sum of the experimentally determined average β, $\overline{\nu}$, and γ energies (accounting for delayed neutron emission) which should add up to the Q_β energy. They make note of 11 nuclides, including ^{84}As, for which serious discrepancies are found between this sum and the Q_β value. One cause of this discrepancy could be an experimental error in the determination of the average β or γ energies. Another cause could be an erroneous Q_β value. The Q_β value for ^{84}As that was compared to the sum was taken from the *Table of Isotopes* [3], which was derived from systematics.

It is the purpose of this paper to report on the direct measurement of the Q_β value of ^{84}As, and to note that this value is in agreement with the sum reported by Rudstam *et al.* [2]. This value also substantially reduces the experimental uncertainty in the Q_β value over that obtained from the average β and γ energy sum.

The Q_β value of $^{84}As \to ^{84}Se$ was measured at the TRISTAN on-line mass separator at the High Flux Beam Reactor at Brookhaven National Laboratory. A high temperature plasma ion source [4], containing about 5 g of highly enriched ^{235}U, was used to produce a beam of mass 84, ~15% of which was ^{84}As. The ion beam was implanted onto the aluminumized mylar tape of a moving tape collector, which was set up to take β-γ coincidences. The tape was moved at 10 s intervals, during the 2 week experiment, to enhance the yield of the shorter-lived As over that of its daughter activities. A planar hyperpure Ge detector with a 500 mm^2 active area, 15 mm deep, and a 12 μm Ti window was used to measure the β spectrum. The β spectrum was taken in coincidence with a large (30%) Ge detector, which selected γ events. This system has been described in detail by Brenner *et al.* [5]. The data were collected in event mode using fast ADCs that interface to a CAMAC-based fast encoded readout ADC bus system. Events were stored in a CAMAC first in, first out buffer and read out, via a small computer system interface bus, to a workstation, and written onto 8 mm tape for later analysis. After sorting the data by selecting the desired γ ray gates, the β end point was determined by Fermi-Kurie analysis, employing the techniques used in the program BDK, as described by Rehfield [6].

Energies of known γ rays [7,8] from the decay of ^{84}As and ^{84}Br, which were observed in the β spectrum, were used to determine the energy calibration and nonlinearity of the Ge β detector. A linear fit to γ rays with energies from 424.0–3927.5 keV was used for this determination. The subsequent extrapolation from this range to the end point introduces an additional uncertainty of about ±2 keV. This uncertainty is included in the final error.

Early studies of the decay of ^{84}As [9] indicated the presence of two β-decaying isomers, with half-lives of 5.5 and 0.65 s. The most recent study of ^{84}As decay was that of Hoff *et al.* [8]. They determined the half-life to be 4.5±0.2 s, but did not confirm the presence of the shorter lived isomer. The Hoff study assigned 67 γ rays to the decay of ^{84}As, and identified 33 excited states in the singly magic ($N = 50$) nucleus ^{84}Se. The present study cannot shed further light on the question of a 0.65 s isomer, as no half-life measurements, or other measurements that could have distinguished between the proposed isomers were attempted.

The β-γ coincidence data were analyzed by gating on the 1454.6 keV γ ray, in the Ge detector, from the $2_1^+ \to 0_1^+$ transition in ^{84}Se. Other γ rays were too weakly populated to provide sufficient statistics for end-point analysis. The end point of the resulting β spectrum thus gives the energy separation of the ^{84}As ground state and the state which lies 1454.6 keV above the ^{84}Se ground state. Since other, higher lying, states feed into the 2_1^+ state, the β spectrum will also contain contributions from these cascades. However, all of these will have a lower end-point energy, and will effect the overall shape of the β spectrum, but not the highest end point. The next lower end point will be 667 keV below that for the 1454.6 keV gate, and has less than half of the β feeding. Therefore, in this case, cascading γ rays will not interfere with the analysis of the end point. The raw data are in a spectrum with a length of 8192 channels. This spec-

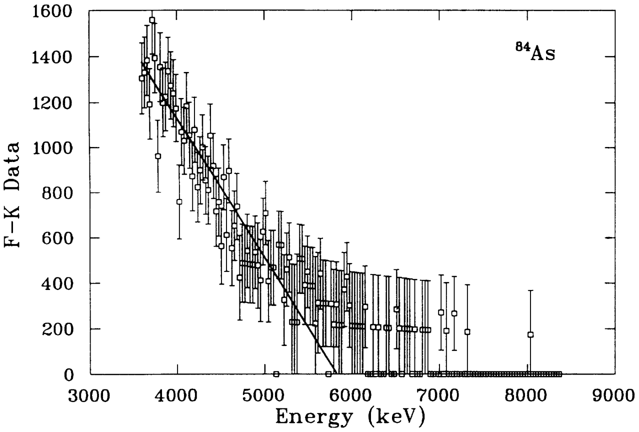

FIG. 1. β spectrum for ^{84}As near the end point. The data, as modified by a Fermi-Kurie function, are plotted vs the energy.

trum was compressed to a length of 2048 channels for the end-point determination. The result of the Fermi-Kurie analysis of the data is shown in Fig. 1, where the line drawn through the data shows the fit which yields the end point. A value of 5740±200 keV is obtained for the end-point energy. When this is added to the excitation energy for the 2_1^+ level, a Q_β value of 7195±200 keV is obtained. The error includes both statistical and estimated systematic errors. The systematic error was estimated by choosing differing, but reasonable, ranges over which the data were fit. The error also includes the uncertainty in extrapolating the energy calibration to the end-point region. The sum of average β and γ energies for ^{84}As that was measured by Rudstam *et al.* [2] was 6840±680 keV, which is in agreement with the measurement of the Q_β value reported here.

Mass calculations tend to overestimate the Q_β value for ^{84}As. Recent calculations by Möller *et al.* [10] give a value of 10.01 MeV. In a 1988 review [11], nine other calculations that give a Q_β value ranging from 9.4–11.0 MeV were reported. Thus, based on the current measurement, there seems to be a systematic overestimation of the size of the shell gap, at $N = 50$, in models that are used to calculate nuclear masses.

A first measurement of the Q_β value for the decay of ^{84}As has been made. This measurement is consistent with the Q_β value inferred indirectly from sums over average β and γ energies but is a direct measurement and also has a much smaller uncertainty. It should provide important input to decay heat estimations. In addition, the systematic overestimation of the Q_β by nuclear mass calculations suggests that, for this nucleus, the influence of the $N = 50$ shell gap may be overestimated.

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