PHYSICAL REVIEW C VOLUME 22, NUMBER 5 NOVEMBER 1980

β^+ decay of ^{67}As

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(Received 27 March 1980)

The β^+ decay of the new isotope ^{67}As to levels in ^{67}Ge has been studied via the reaction $^{58}\mathrm{Ni}(^{14}\mathrm{N},\alpha n)^{67}\mathrm{As}\xrightarrow{\beta^+}{}^{67}\mathrm{Ge}$ using 39- and 41-MeV ^{14}N ions. The ^{67}As half-life and total decay energy (Q_{EC}) have been measured to be 42.5 ± 1.2 s and 6.01 ± 0.10 MeV, respectively. The β^+ decay scheme to 15 levels up to 2524-keV excitation in ^{67}Ge has been determined and, based on measured log*ft* values, a spin/parity constraint of $3/2^-$ or $5/2^-$ for the ground state of ^{67}As has been established.

RADIOACTIVITY ^{67}As [from $^{58}\mathrm{Ni}(^{14}\mathrm{N},\alpha n)$]: measured $T_{1/2}$, E_γ, I_γ, γ-γ coin, E_{β^+}, β^+-γ coin; deduced decay scheme, mass excess, logft values, J^π restrictions; ^{67}Ge J^π restrictions. Enriched targets, multiple rabbit, helium jet, Ge(Li) and plastic detectors.

I. INTRODUCTION

^{67}As is a newly discovered neutron-deficient isotope which decays by positron emission and electron capture to excited states of ^{67}Ge. Its observation was first reported by the authors in 1976;[1] the details of its decay scheme appear here for the first time. The level scheme of the daughter nucleus was unknown when this work was begun, so that a separate investigation of ^{67}Ge excited states and γ rays was necessary in order to identify ^{67}As and establish its decay scheme. The results for ^{67}Ge are reported in Refs. 2 and 3.

The study of new nuclei far from β stability, such as ^{67}As, is important to current research in stellar evolution and nucleosynthesis. By way of illustration, the cores of highly evolved, massive stars contain nuclei up to $Z \approx 35$, with the iron group playing a major role; core conditions can cause these nuclei to capture electrons and become neutron-rich.[4] Any attempt to model the evolution of such a star therefore requires empirically based systematic descriptions of nuclei far from stability. The discovery of ^{67}As provides a look at the properties of one of the iron group nuclei farthest from stability. Not only do the new data enlarge the base upon which nuclear mass formulas and general models of β decay are built, but they can also help determine the applicability of a particular one of these formulas to a specific astrophysical problem.

The half-life, decay scheme, and mass excess of ^{67}As have been determined from β-delayed γ-ray singles and γ-γ coincidence, and β-γ coincidence measurements. On the basis of logft values obtained for the β^+ branches to ^{67}Ge states of known spin and spin systematics of odd-A As isotopes, a tentative spin assignment may be made to the ^{67}As ground state. This assignment, in conjunction with other logft's measured for ^{67}As β^+ decay, provides constraints on the spins and parities of ten additional levels in ^{67}Ge. The newly determined mass of ^{67}As agrees with theoretical predictions, and the decay scheme is found to have similarities with that of ^{69}As.

II. EXPERIMENTAL PROCEDURES

^{67}As was produced via the reaction $^{58}\mathrm{Ni}(^{14}\mathrm{N},\alpha n)\,^{67}\mathrm{As}$, using ^{14}N ions from the Argonne FN tandem Accelerator. The ^{58}Ni targets were self-supporting 1.5 and 5.0 mg/cm^2 foils enriched to ~98%. In each run the reaction products were transferred to a remote, shielded counting area to minimize background from the beam and prompt γ rays. The experimental data were recorded on-line by a PDP 11/45 computer, and the γ-ray detectors were calibrated in energy and efficiency with a mixed radionuclide source obtained from the National Bureau of Standards. This source includes ^{109}Cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{113}Sn, ^{137}Cs, ^{60}Co, and ^{88}Y.

In the first run, singles measurements of β-delayed ^{67}Ge γ rays were made using both an intrinsic germanium and a 15% coaxial Ge(Li) detector. Targets were irradiated with 39-MeV ^{14}N ions for periods of 20 s (based upon an expected ^{67}As lifetime of ~40 s) and then pneumatically transferred to the shielded counting area via a "multiple rabbit" transfer system.[5] This system permits the cyclic bombardment and transfer of up to eight targets, thus inhibiting the buildup of long-lived contaminants. The 4096-channel pulse-height spectra collected after each 20 s bombardment period were routed into eight consecutive 20-s time bins in order to measure the ^{67}As half-life. Gamma-ray yields in each time bin were corrected for computer dead time by separately scaling a pulser gated by the busy signal from the data-acquisition system. In this and subsequent runs, the target transfer system and routing of spectra were operated by a crystal-controlled sequence timer.

A γ-γ coincidence measurement was made next, to further identify and determine the order of ^{67}Ge γ rays from the decay of ^{67}As. The ^{58}Ni + ^{14}N reaction was run at 41 MeV, and the remote transfer of activity was done with a helium jet transfer system. A 22 cm^3 semiplanar and a 15% coaxial Ge(Li) detector were placed 180° apart, and about 1 cm from the activity to maximize efficiency and minimize correlation effects. A bombardment and count cycle based upon the ~40 s half-life of ^{67}As was again used, and the helium jet virtually eliminated all long-lived activity. The coincidence timing circuit used a time-to-amplitude converter (TAC) with typical coincidence count rates of ~500 s^{-1}. With these parameters, pileup and dead time were not significant. The data were sorted on-line into 4096-channel spectra and recorded event by event on magnetic tape for later analysis.

For the β^+-γ coincidence experiment, which measured the β^+ end point of ^{67}As, 41-MeV ^{14}N ions and a 1.5 mg/cm^2 ^{58}Ni target were used to make ^{67}As. The reaction products were transferred to a shielded counting area by the multiple rabbit transfer system. In each experimental cycle, the target was irradiated for 40 s, and then the radioactive products were counted for a period of 80 s, with the beam off. A 15% efficient coaxial Ge(Li) detector was used to observe γ rays, and a 7-cm diameter by 4.4-cm deep NE102 plastic scintillator coupled to an RCA 8575 phototube was used to record positrons. Both detectors were in close geometry, and the Ge(Li) detector was screened from positrons by a 0.625 cm Lucite absorber. The detectors were operated in coincidence using a time-to-amplitude converter. The average scintillator count rate was ~40 000 s^{-1}, and the coincidence count rate was ~2000 s^{-1}. To reduce pileup at these rates, a pileup rejection circuit using commercially available electronics was included in the scintillator circuit. The coincident energy signals of both detectors, and the coincidence time parameter, were sorted on-line by a PDP 11/45 computer and also recorded event by event on magnetic tape.

III. ANALYSIS AND RESULTS

The ^{67}Ge level scheme reported in Refs. 2 and 3 was determined in part from the results of the γ-ray singles and γ-γ coincidence measurements described here, and consequently contains all γ rays and excited states observed in the β^+ decay of ^{67}As. Rather than repeating here all of the procedures used to establish the ^{67}Ge level scheme, only the results pertinent to ^{67}As decay will be discussed.

A. The decay scheme of ^{67}As

Figure 1 shows the delayed γ-ray singles spectra from the ^{58}Ni + ^{14}N reaction, observed with the 15% Ge(Li) detector during the first 20 s time bin. Both the multiple rabbit (39 MeV) and helium jet (41 MeV) spectra are shown for comparison. Inset in this figure is a segment of the intrinsic detector spectrum detailing the doublet at 122 keV. Prominent γ rays from each of the principal contaminants are identified by nucleus, and γ rays from ^{67}As decay are noted by energy. The γ rays of energies 104.4, 120.8, 122.7, 225.4, 243.6, 685.5, 789.9, and 808.1 keV were previously known to be from low-lying levels in ^{67}Ge.[2]

After extracting their net yields from each 20-s time bin and correcting for dead time, the 104.4, 120.8, and 122.7 keV γ rays were observed to decay with half-lives of 41.8 ± 3.7, 43.0 ± 2.5, and 42.4 ± 1.5 s, respectively. From these measurements the half-life of ^{67}As was determined to be 42.5 ± 1.2 s. The other γ rays in Fig. 1 identified with ^{67}As decay have lifetimes consistent with 40 s and also satisfy the energy sum and coincidence relations specified by the decay scheme to be discussed later.

Gates were set in the γ-γ coincidence data on thirteen of the ^{67}As decay γ rays seen in singles, and the spectra of γ rays in coincidence with them were generated. Coincidences with the Compton background were eliminated from each spectrum by setting background gates on either side of the peak and subtracting their properly averaged yield from the peak gate. Figure 2 shows the resulting spectrum in coincidence with the 122-keV transition. The coincidence grid obtained from these data, listing only those γ rays placed in the ^{67}As decay scheme, is shown in Table I. A complete tabulation of all ^{67}As decay γ rays is provided in Table II.

In order to obtain the relative intensities of the ^{67}As decay γ rays, their yields were extracted from the γ-ray singles and, in some cases, the γ-γ coincidence spectra. In those instances where ^{67}As γ rays formed doublets in the singles spectrum with γ rays from contaminants, the contaminating peak was subtracted out to obtain the ^{67}As γ-ray yield. (Two subtraction procedures were used: If the contaminant γ ray had a lifetime much longer than ^{67}As, then the doublet yields in the last four time bin spectra were summed and subtracted from the sum of the first four time bins, with a

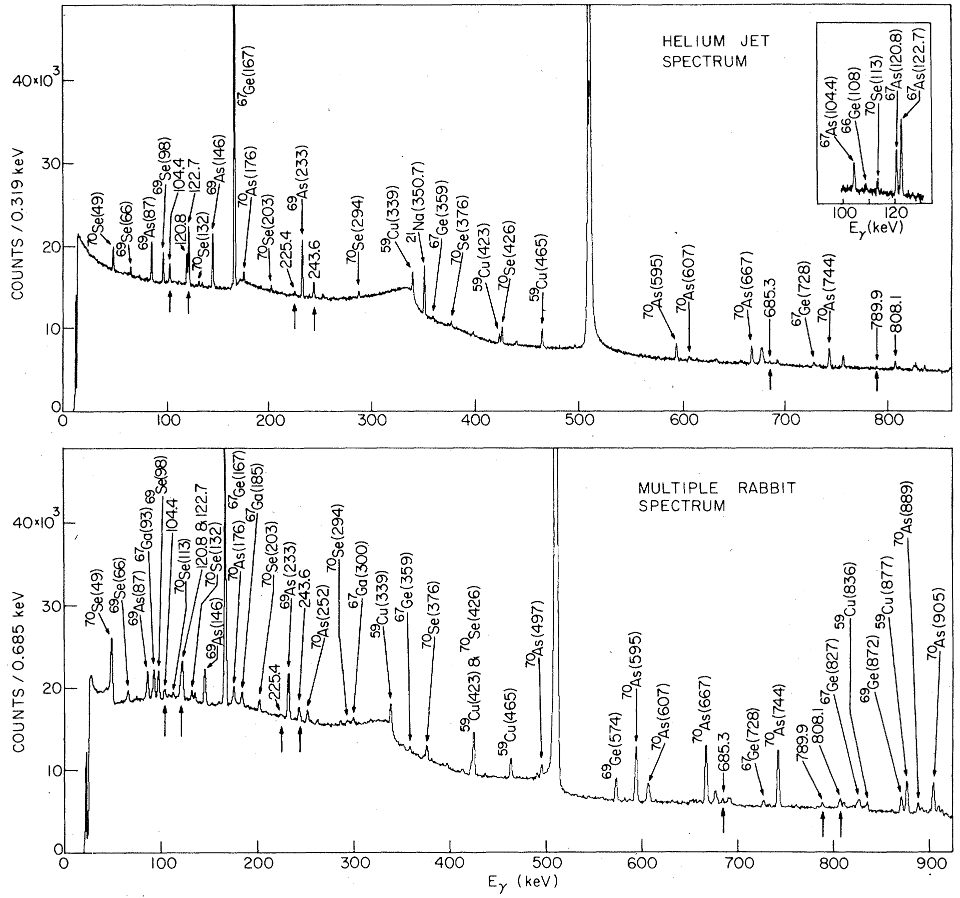

FIG. 1. The spectrum of beta-delayed gamma rays observed in singles with a 15% Ge(Li) detector in the first 20 s time bin following the ^{58}Ni+^{14}N reaction at 41 and 39 MeV. The inset shows a segment of the spectrum observed with an intrinsic Ge detector. ^{67}As decay gamma rays are identified by energy and by arrows below the peaks.

small correction for the finite lifetime of the contaminant. If the contaminant lifetime was <100 s, then the intensity of the doublet γ ray was calculated from the observed yield of another γ ray from the contaminant having a known intensity relative to the one in the doublet.) The yields of the ^{67}As γ rays were then corrected for detector efficiency and all coincident summing in the detectors to obtain the true γ-ray intensities.

The relative intensities of those γ rays seen only in coincidence spectra were obtained by normalizing their measured intensities to that of a prominent γ ray in the coincidence spectrum which was also seen in the singles spectrum. In each of these cases, the energies of the γ ray of unknown intensity and the reference γ ray were >500 keV—it was therefore assumed that the relative efficiencies of the detectors were unaffected by the coincidence circuitry. For gamma rays observed in more than one spectrum, the weighted average of

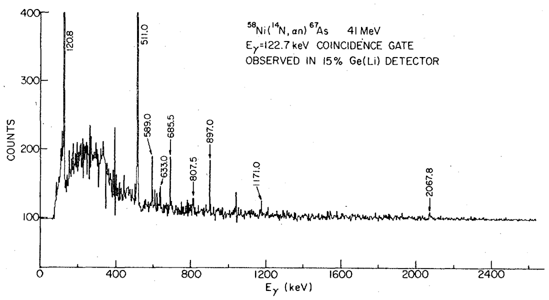

FIG. 2. The background-corrected spectrum of beta-delayed gamma rays in coincidence with the 122.7-keV gamma ray from ^{67}As decay. This spectrum was observed with a 15% Ge(Li) detector, following the ^{58}Ni(^{14}N, αn)^{67}As reaction at 41 MeV. The weakest gamma rays in this spectrum were also observed in other coincidence measurements.

TABLE I. Coincidence matrix for gamma rays placed in the ^{67}As beta-decay scheme (x = definite, p = possible).

E_γ (keV)	104.4	120.8	122.7	243.6	248.0	589.0	633.0	685.5	776.0	789.9	808.1	897.4	1049.6	1151.4	1171.3	1274.3	1576.0	1657.0	2128.4	2280.4
104.4		x				x		x				x		x	x					
120.8	x		x				x		x				x					x		x
122.7		x				x	x	x	x	p	x	x			x		x			
243.6													x			x			x	
589.9	x	x																		
633.0	x	x	x		x															
685.5	x		x																	
776.0		x	x																	
789.9			p																	
808.1																				
897.4	x		x																	
1171.0	x		x																	
1576.0			x																	

the intensities was taken for the final value.

In the case of the 18.2-keV level in ^{67}Ge, the intensity of the 18.2-keV γ transition was obtained in an indirect manner. An earlier measurement of prompt γ rays from ^{67}Ge had shown[2] that the 18.2-keV level has a total mean lifetime of 18.5 ± 0.3 μs and is strongly converted ($\alpha_K = 176 \pm 29$); consequently the 18.2-keV $E2$ γ ray was not seen in either γ-γ coincidence or delayed singles spectra. However, the singles spectrum obtained with the intrinsic detector showed a strong yield of Ge K x rays (Fig. 3). All of the longer-lived x rays associated with ^{70}As, ^{69}Ge, ^{67}Ga, and ^{66}Ga were subtracted from this spectrum. The Ge K x-ray yield was then corrected for contributions from electron capture decay of ^{67}As and conversion of levels in ^{67}Ge above 18.2 keV. (The conversion coefficients for the 104, 120, 122, and 243 keV $M1/E2$ transitions in ^{67}Ge were evaluated using the newly measured mixing ratios reported in Ref. 3.) The net Ge K x-ray yield was attributed to conversion of the 18.2-keV level. In order to calibrate the efficiency of the intrinsic germanium

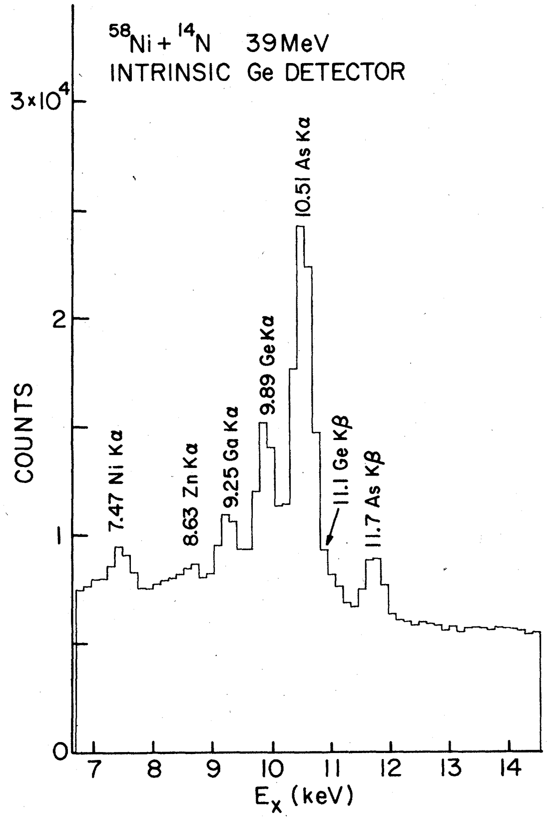

FIG. 3. The spectrum of x rays observed with the intrinsic germanium detector, following the ^{58}Ni+^{14}N reaction at 39 MeV. This spectrum was recorded during the first 20 s counting period. Part of the yield of Ge K_α and K_β x rays is from the internal conversion of the 18.2-keV level in ^{67}Ge.

TABLE II. Energies and intensities of γ rays placed in the ^{67}As decay scheme.

E_γ (keV)	$\frac{I_\gamma}{I_{122}}\times 100$	E_γ	$\frac{I_\gamma}{I_{122}}\times 100$
18.2 ± 0.05	0.83 ± 0.15	808.1 ± 0.3	32.1 ± 6.0
104.4 ± 0.3	23.7 ± 0.6	897.4 ± 0.3	16.1 ± 5.0
120.8 ± 0.3	49.6 ± 1.0	1049.6 ± 1.0	1.5 ± 0.7
122.7 ± 0.3	100	1151.4 ± 0.5	3.0 ± 1.1
225.4 ± 0.3	7.7 ± 0.8	1171.3 ± 0.5	7.8 ± 2.3
243.6 ± 0.3	40.3 ± 2.3	1274.3 ± 1.0	7.0 ± 3.0
248.0 ± 0.3	7.6 ± 3.1	1294.0 ± 0.5	7.4 ± 5.5
589 ± 0.3	10.3 ± 1.1	1385 ± 1.0	1.7 ± 0.9
633.0 ± 0.3	13.0 ± 3.0	1576.9 ± 1.0	3.7 ± 1.8
685.5 ± 0.3	11.7 ± 2.9	1657.0 ± 0.5	2.0 ± 1.0
693.1 ± 0.5	25.2 ± 3.0	2128.4 ± 1.0	2.0 ± 1.0
776.4 ± 0.3	5.0 ± 4.0	2218.2 ± 1.0	20.3 ± 6.9
789.9 ± 0.3	24.8 ± 7.7	2280.0 ± 1.0	1.5 ± 0.9

detector at Ge x-ray energies (9.89 and 11.1 keV) it was necessary to make an ^{73}As calibration source, the decay of which provided Ge x rays of known intensity. Using $\alpha_K = 187$ for the K conversion coefficient,[6] and the recently measured Ge K-fluorescence yield $\omega_K = 0.561 \pm 0.015$,[7] the intensity of the 18.2 keV γ ray was determined to be $(8.3 \pm 1.5)\times 10^{-3}$, relative to the strong 122.7 keV γ transition. All of the ^{67}As decay γ-ray intensities, normalized to the 122.7-keV γ ray, are summarized in Table II.

The β^+ feeding to each excited state of ^{67}Ge was obtained from the difference in the total number of transitions (γ and internal conversion) to and from the state. For those states where the balance of transition intensities provided a result consistent with zero, an upper limit on the β^+ feeding (and a corresponding lower limit on logft) was established from the uncertainties in the transition strengths. The experimental method did not permit a measurement of direct feeding to the ^{67}Ge $\frac{1}{2}^-$ ground state. However, there is convincing evidence that the ground-state spin of ^{67}As is $\frac{5}{2}^-$ (see Sec. IV), in which case the β^+ branch to the ground state has a negligible strength. The relative strengths (I_{β^+}) of the observed β^+ branches, and the resulting logft's, have been computed assuming zero feeding to the ^{67}Ge ground state.

For each ^{67}As β-decay branch, the combined logft for positron decay and electron capture was evaluated using the measured β^+ end point energy $E_{\max}(\beta^+) = 4.99 \pm 0.10$ MeV (see the following section), the measured ^{67}As total half-life of 42.5 ± 1.2 s, and the log$f$ tables of Gove and Martin.[8] Figure 4 shows the ^{67}As decay scheme deduced from these observations.

B. The mass of ^{67}As

The mass of ^{67}As was determined from the β^+ end point energy measured in the β^+-γ coincidence experiment. Of the observed ^{67}As β^+ decay branches (Fig. 4), only the one to the 243.6-keV level in

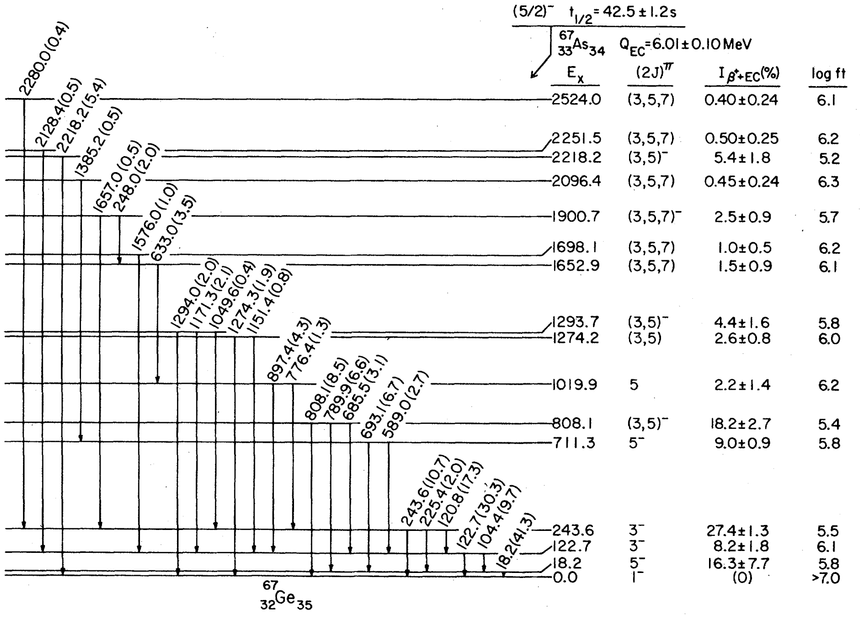

FIG. 4. The β^+ decay scheme for ^{67}As. The gamma-ray intensities are given per 100 ^{67}As decays. The spins of the ^{67}Ge ground state and levels at 18.2, 122.7, 243.6, 711.3, and 1019.9 keV were determined by the angular distributions and correlations reported in Ref. 3. The other spin constraints are based on the observed logft's and the $\frac{5}{2}^-$ assignment to the ^{67}As ground state.

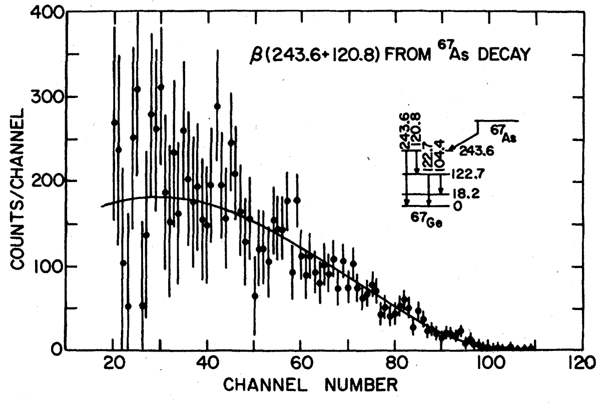

FIG. 5. The background-corrected summed spectrum of positrons in coincidence with the 120.8- and 243.6-keV gamma rays from ^{67}As decay, observed in a plastic scintillator. The solid curve is the best fit to the data using the shape-fitting procedure.

^{67}Ge was strong enough to provide adequate statistics for the end point measurement. Gates were set on the ^{67}As gamma-ray peaks at 120.8 and 243.6 keV in order to obtain the β^+ spectra in coincidence with each of these gamma rays. (The $E_\gamma = 120.8$-keV gate was constrained to channels below 121.0 keV to avoid including positrons in coincidence with the 122.7-keV γ ray.) Accidental coincidences were minimized by setting a 30 ns wide window on the peak of the TAC time spectrum. Background gates were set on either side of each gamma peak and subtracted from the peak gate to eliminate all events in coincidence with the Compton background. The 243.6-keV spectrum was contaminated by positrons in coincidence with the 244.14-keV γ ray from the decay of ^{70}Se. In order to correct for this ^{70}Se contribution, it was noted that there is a 293.6-keV γ ray from the same level as the 244.14, and that both have the same intensity.[9] Thus the β^+ spectrum in coincidence with 293.6, when corrected for detector and coincidence efficiency, is equal to the β^+ spectrum in coincidence with the 244.14-keV γ ray. The 293.6-keV spectrum was obtained from the data, multiplied by the efficiency corrections, and subtracted from the 243.6-keV spectrum. The 120.8- and corrected 243.6-keV spectra were then added together. The total spectrum is shown in Fig. 5.

The β^+ end point of ^{67}As was determined by applying a shape-fitting procedure[10] to the total β^+ spectrum for the 243.6-keV level. This technique is based upon the empirically justified assumption that the β^+ spectra of similar nuclei observed under identical experimental conditions will be identical apart from vertical and horizontal scale factors. The horizontal scale (or stretch) factor is proportional to the end point energy. The basic advantage of this procedure is in its implicit accommodation of, e.g., the response function of the scintillator and the effects of edge losses and backscattering in both detectors. The underlying assumption is that systematic errors associated with each of these corrections are approximately independent of energy over a reasonable range of end point energies.

To apply the method, the β^+ spectra of several nuclei which are made at the same time as the nucleus of unknown end point, and which have well known end points, are obtained from the data. These comprise the energy calibrators; the one with the best statistical shape is then smoothed and the result is designated as the standard shape. These calibration spectra, and especially the standard, should be essentially pure β^+ branches. The standard is multiplied by vertical and horizontal parameters and used as a fitting function. The other calibrator spectra and the spectrum with the unknown end point are then fitted by a least squares procedure to the standard, and the horizontal stretch factors obtained. A plot of the calibrator stretch factors versus their known β^+ end points should be a straight line; the corresponding point for the unknown spectrum will also lie on this line.

In this experiment the ^{58}Ni + ^{14}N reaction produced ^{59}Cu, ^{69}As, ^{70}As, and ^{67}Ge, in addition to ^{67}As. The β^+ decay schemes of each of these nuclei have one or more branches of well-known end point energy to states which are not significantly fed from above. The five branches used as calibrators are shown in Fig. 6. Gates were set on the five calibrator gamma rays, and the coincident β^+ spectra were obtained in the same fashion as for ^{67}As. The ^{67}Ge branch to the 167-keV level in ^{67}Ga was taken as the standard and a curve was hand drawn through the spectrum, shown in Fig. 7. The calibration spectra were then fitted with the ^{67}Ge standard. The reduced χ^2 for the calibrator fits, their stretch factors S, and the corresponding end points are summarized in Table III; a plot of stretch factor versus end point is shown in Fig. 8. The five calibration points fit a straight line with reduced $\chi^2 = 0.356$.

The ^{67}As β^+ spectrum in coincidence with the 120.8- and 243.6-keV gamma rays has a 90% contribution from direct feeding to the level at 243.6 keV, and 10% from higher levels (Fig. 4). The indirect feeding and the effects of coincident gamma rays entering the scintillator may be accommodated in the shape-fitting technique, but were found to be insignificant factors in the summed 243.6-keV spectrum of ^{67}As. The fit to the total

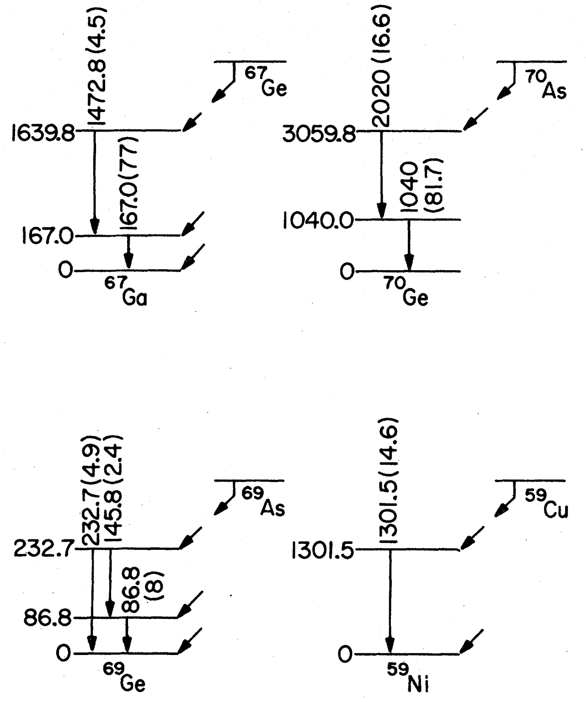

FIG. 6. The β^+ branches of the nuclei whose observed positron spectra and known end points were used as calibrators for the shape-fitting procedure. (The gamma-ray intensities are noted in parentheses.)

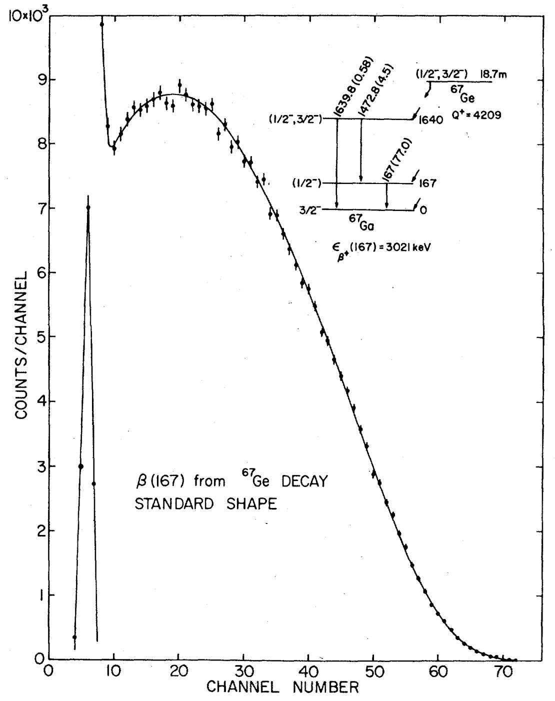

FIG. 7. The positron spectrum from the decay of ^{67}Ge to the 167-keV level in ^{67}Ga. This spectrum was used as the standard shape; the solid curve is a hand-drawn fit to the data.

243.6-keV spectrum (Fig. 5) yielded a stretch factor $S = 1.547 \pm 0.011$ at a reduced $\chi^2 = 0.807$. From an extrapolation of the straight line fit to the calibrations, the ^{67}As β^+ end point to the ground state of ^{67}Ge was determined to be 4.99 ± 0.10 MeV. The uncertainty includes a 75-keV systematic uncertainty in the shape-fitting procedure. Taking for the mass of ^{67}Ge the recently measured value −62.666 ± 0.012 MeV,[2] this end point corresponds to a mass excess of −56.65 ± 0.10 MeV for ^{67}As.

IV. SPINS AND PARITIES

The ^{67}Ge in-beam gamma-ray measurements reported in Ref. 3 have established the spins and parities of the ^{67}Ge levels up to 711.3 keV, and the spin of the level at 1019.9 keV. The new spin/parity assignments and constraints discussed here are based upon the observed log*ft* values in ^{67}As β^+ decay and have been made according to the log*ft* rules of Raman and Gove.[11]

TABLE III. The β^+ end points and stretch factors for the calibrators and for ^{67}As.

Nucleus	E^* (keV)	Stretch factor	χ_ν^2	$E_{\max}(\beta^+)$ keV
^{67}Ge	1640	0.514 ± 0.023	1.2	1548 ± 13
^{70}As	3060	0.722 ± 0.008	2.8	2140 ± 20
^{59}Cu	1301.5	0.835 ± 0.009	1.0	2476 ± 11
^{69}As	232.7	0.903 ± 0.016	1.1	2710 ± 50
^{67}Ge	167.0	1.000 ± 0.004		3021 ± 13
^{67}As	243.6	1.547 ± 0.011	0.8	4740 ± 100

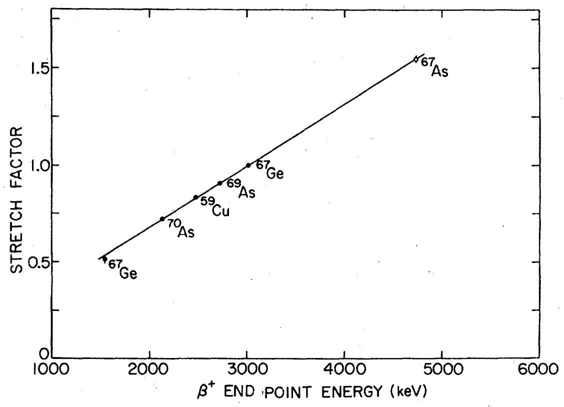

FIG. 8. A plot of the horizontal stretch factors S of the five calibration β^+ branches versus their known β^+ end points. The point for the ^{67}As branch to the 243.6-keV level in ^{67}Ge is also indicated.

A. The ground state of $^{67}_{33}\mathrm{As}_{34}$

In the decay scheme for ^{67}As (Fig. 4) two of the strongest β^+ branches are to known $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states of ^{67}Ge. If the ground state spin of ^{67}As were $\frac{1}{2}$, then one of its strongest β^+ decay channels would be either a first-forbidden unique, or a second-forbidden nonunique transition. It is inconceivable that ^{67}As has no allowed beta transitions, or that none of its allowed decay channels is stronger than a $\Delta J = 2$ transition. Thus the ground state spin of ^{67}As must be $\frac{3}{2}$ or $\frac{5}{2}$.

In a single-particle configuration, the valence nucleon in odd-A As isotopes is an $f_{5/2}$ proton, which would provide a ground-state spin of $\frac{5}{2}$. Although the single-particle model is not a reliable guide to the spins of nuclei in this mass region, it is observed in the previously known odd-A As level schemes that the $\frac{5}{2}$ ground state is found in the lighter ($A \leq 71$) isotopes. For $A \geq 73$ the ground state spin is $\frac{3}{2}$. This trend suggests that in the heavier As isotopes the pairing force for for protons is stronger than the $p_{3/2}$-$f_{5/2}$ level spacing, so that in the ground state a hole is created in the proton $p_{3/2}$ shell in order to pair off the valence $f_{5/2}$ proton. For $A < 73$, the relative strength of the pairing diminishes, and single particle-type configurations predominate. These observations strongly favor a ground-state spin of $\frac{5}{2}$ for ^{67}As.

Given the systematic evidence, ^{67}As is tentatively assigned a ground state spin of $\frac{5}{2}$. Its β^+ decay to the $\frac{1}{2}^-$ ground state of ^{67}Ge is then a $\Delta J = 2$ transition. Such transitions would not be expected to have an observable strength, and it is reasonable to assume zero feeding to the ^{67}Ge ground state. The logft's have been computed under that assumption. The β^+ branches to the ^{67}Ge $\frac{5}{2}^-$ and $\frac{3}{2}^-$ states at 18.2 and 243.6 keV, with logft's <5.9, are therefore allowed transitions, which establishes negative parity for the ^{67}As ground state.

B. Spins and parities of ^{67}Ge excited states

Table III and the decay scheme in Fig. 4 contain the ^{67}Ge spin/parity determinations which have been made on the basis of measured logft's and the tentative ^{67}As spin of $\frac{5}{2}^-$. In all cases, the largest logft allowed by the uncertainty in the level feeding has been used in applying the rules of Raman and Gove.[11] A spin assignment or constraint has been made only where the logft conclusively indicates a $\Delta J = 0$ or 1 β^+ transition. Gamma transitions of less than 2 MeV with $L \geq 3$ multipolarity are unlikely; therefore the spins of those levels observed to decay via γ transitions to the $\frac{1}{2}^-$ ground state have been further constrained to $\frac{3}{2}$ or $\frac{5}{2}$.

V. DISCUSSION

The observed branches for the β^+ decay of ^{67}As to ^{67}Ge restrict the ground state spin of ^{67}As to either $\frac{3}{2}$ or $\frac{5}{2}$, but are not sufficiently documented to uniquely specify the spin. The tentative assignment of $\frac{5}{2}^-$ has been based on a systematic trend in odd-A As ground state spins, and is the justification for assuming that there is negligible feeding to the ^{67}Ge ground state. All of the spin/parity constraints placed on levels in ^{67}Ge on the basis of logft's are dependent on the $\frac{5}{2}^-$ assignment to ^{67}As. The identification of either a $J = \frac{1}{2}$ or $J = \frac{7}{2}$ level in ^{67}Ge fed by β^+ decay and with a log$ft \lesssim 7.0$ would conclusively determine the spin of ^{67}As.

The decay of ^{67}As to the lowest energy states of ^{67}Ge is similar to the β^+ decay of ^{69}As to ^{69}Ge.[12] The ^{67}As branch to the first $\frac{5}{2}^-$ state of ^{67}Ge has a logft of 5.8, while the corresponding branch for ^{69}As has a logft of 5.4. Of the ^{67}As branches to the two lowest $\frac{3}{2}^-$ levels in ^{67}Ge, one is favored 77% of the time. In ^{69}As decay the analogous branching ratio is 80%.

The mass excess of ^{67}As has been measured to be -56.65 ± 0.10 MeV. A comparison of this mass with several predictions[13] (Table IV) shows that the measured value falls in the middle of the seven predictions. Of the various predictions, those based on the shell model and the Garvey-Kelson mass relations (denoted by LZ, JGK, and CK in Table IV) are in better agreement with the measurement than those employing semiempirical liquid drop models (Myers, GHT, and SH). The same observation has been made with regard to

TABLE IV. Comparison of measured ^{67}As mass excess with predictions.

Predicted ^{67}As mass excess (ΔM) in MeV	
Model	ΔM
Myers[a]	−57.03
GHT[b]	−57.14
SH[c]	−56.2
LZ[d]	−56.33
JGK[e]	−56.54
CK[f]	−56.34
JE[g]	−57.02
Measured mass excess	
This work	-56.65 ± 0.10 MeV

[a] W. D. Myers, Ref. 13.

[b] H. V. Groote, E. R. Hilf, and K. Takahashi, Ref. 13.

[c] P. A. Seeger and W. M. Howard, Ref. 13.

[d] S. Liran and N. Zeldes, Ref. 13.

[e] J. Janecke, Ref. 13.

[f] E. Comay and I. Kelson, Ref. 13.

[g] J. Janecke and B. P. Eynon, Ref. 13.

the ^{67}Ge mass.[2]

This study of ^{67}As has been motivated by astrophysical problems which involve the physics of nuclei far from β stability; part of its usefulness is in the development and validation of general formulas for nuclear masses and β-decay systematics. When used to test the accuracy of currently available formulas for gross nuclear properties, new experimental data can point up important distinctions between the various types of predictive systematics, according to the basic nuclear models from which they are derived. For example, it has been found that the newly measured masses of ^{67}As and ^{67}Ge are in significantly better agreement with shell-model-based mass predictions than with those based on the liquid drop model. The known masses of iron-group nuclei closer to stability also tend to favor the shell-model predictions. This observation indicates that, if liquid drop models of the nuclear binding energy do ultimately become a (relatively) more accurate means of mass prediction as one departs from β stability, the transition occurs farther from stability than the region near ^{67}As. Such a distinction should be considered when choosing the mass formula for a particular astrophysical calculation.

ACKNOWLEDGMENTS

The authors would like to thank Richard C. Pardo and John P. Schiffer for critical readings of the manuscript. This work was performed under the auspices of the U. S. Department of Energy.

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