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GERMANIUM-64

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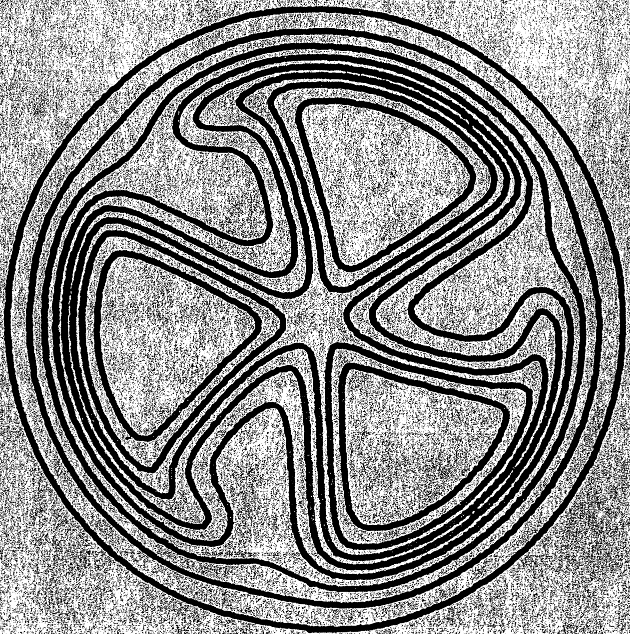

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Germanium-64

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ABSTRACT

The new isotope ^{64}Ge has been produced via the ^{64}Zn(^{3}He,3n)^{64}Ge reaction, chemically isolated and its decay studied. Since ^{64}Ge is therefore nucleon-stable it can in principle have an important role in the synthesis of mass 64 by α capture during explosive stellar events, as proposed by Arnett, Truran, and Woosley. However, from the measured half-life (62.3 ± 2.0 sec) and β-decay systematics it appears that this mechanism is probably responsible for a negligible fraction of the observed abundance of mass 64.

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Recently Arnett, Truran, and Woosley[1] (ATW) have shown that the elements on the high-mass side of the iron peak in the elemental abundance curve can be synthesized in an explosive stellar event. The process involves, for example a quasi-equilibrium among ^{4}He, ^{56}Ni, ^{60}Zn, and ^{64}Ge, and the resulting abundances for mass 60 and 64 depend primarily on the corresponding binding energies. Since ^{64}Ge has never been observed experimentally, ATW used for that isotope a value of the binding energy calculated by Garvey <u>et al</u>.[2] The abundances obtained[1] for masses near 64 are typically two orders of magnitude smaller than those observed in nature.

This discrepancy could possibly be removed if ^{64}Ge were more tightly bound, since production of that nuclide by radiative alpha capture would then be enhanced. In that hope, a number of intensive searches for ^{64}Ge were undertaken[3-7] with a view to obtaining an experimental estimate of its mass. The fact that none of these searches was successful raised doubts about the nucleon-stability of ^{64}Ge and its possible contribution to the synthesis of mass 64.

This Letter reports the detection of ^{64}Ge produced via the ^{64}Zn(^{3}He,3n)^{64}Ge reaction near 50 MeV. Conclusive identification has been made by a) chemical separation of germanium, b) observation of γ rays from the decay of ^{64}Ge to known excited states in the daughter nucleus ^{64}Ga, and c) observation of the growth of the daughter activity.

In view of the expected low yield from the $^{64}Zn(^{3}He,3n)^{64}Ge$ reaction, it is fortunate that the ground state of ^{64}Ga is 0^{+} (Ref. 8), since the isospin selection rule[9] then requires most of the β decay of ^{64}Ge to lead to excited states in ^{64}Ga. Furthermore, one expects the $^{64}Zn(p,n)^{64}Ga$ reaction to populate many of the same states. Gamma rays from that reaction have been studied in-beam by the present authors,[10] by Davids et al.[11] and by Hansen.[12] The latter two investigations included threshold measurements, and a level scheme for ^{64}Ga has been constructed[11,12] on that basis.

Sources of ^{64}Ge were prepared by irradiating 10 mg/cm^{2} targets of 99.66% enriched ^{64}Zn on thick copper backings with the ^{3}He beam from the Michigan State University Cyclotron. The beam energy was degraded from 70 to 50 MeV with a Zn absorber. Following a 2 min irradiation the target was transported by pneumatic "rabbit" to a laboratory where (adapting the method of Porile[13]) the ^{64}Zn was dissolved in concentrated HCl containing $KClO_3$. The volatile $GeCl_4$ was vacuum-distilled at room temperature into a cold trap in front of a Ge(Li) detector. No evidence of activities other than germanium isotopes and their daughters was seen in the spectra except for ^{10}C, which also forms a volatile tetrachloride. Counting was begun approximately 25 sec after the end of irradiation and continued for eight periods of 50.0 sec each.

Figure 1 shows portions of the 0-50 sec and 100-150 sec spectra resulting from a total of 12 irradiations. The strongest lines decay with a short half-life (30±2 sec) and are attributed to ^{65}Ge (despite the large disagreement with the previous half-life[13]), on the basis of the rapid growth of the ^{65}Ga daughter and the good energy fit with levels observed[14] in ^{64}Zn(^{3}He,d)^{65}Ga.

Other lines, at 128.2±0.2, 384.1±0.3, 427.0±0.3, 667.1±0.3, and 774.5±0.3 keV, decay with a (weighted average) half-life of 62.3±2.0 sec and are assigned to the decay of the new isotope ^{64}Ge. All of these lines have been seen in the ^{64}Zn(p,nγ)^{64}Ga experiments. A relative excitation function for ^{64}Ge and ^{65}Ge shows that lines from ^{64}Ge are weak at 29 MeV and undetectable at 20 MeV (the calculated threshold[2] is 21 MeV), while the ^{65}Ge γ rays remain strong. From the known excitation function for the ^{64}Zn(^{3}He,n)^{66}Ge reaction,[5] the cross-section for ^{64}Zn(^{3}He,3n)^{64}Ge at 50 MeV is estimated to be 50 μb.

In Fig. 2 are shown the decay of the 427 keV line from ^{64}Ge, and the growth and decay of the 992 keV line from the daughter ^{64}Ga, whose half-life is 159±2 sec.[15] Correction has been made for weak γ rays of 427 keV in the decays of ^{66}Ge and ^{64}Ga.

With the help of the ^{64}Zn(p,nγ)^{64}Ga results, a decay scheme for ^{64}Ge has been deduced as shown in Fig. 3. Absolute γ-ray intensities have been obtained by normalizing to the measured growth of ^{64}Ga daughter activity. Provided none of the observed γ rays is in cascade or appreciably converted, 79±10% of the decay of ^{64}Ge has been accounted for. The 86 keV line is masked in these experiments by Pb x rays, and the 43 keV line lies below the ADC threshold. The 667 keV γ ray originates below 930 keV excitation[12] in ^{64}Ga, and the 775 below 1460 keV, but their exact locations are not known. Spin-parity assignments of 1^+ have been made where log ft values indicate an allowed β transition. The log ft values shown have been calculated assuming mass excesses ΔM of -58.83 MeV[11] for ^{64}Ga and -54.03 MeV[2] for ^{64}Ge. This mass excess for ^{64}Ge seems quite realistic because the ft values so obtained are similar to those in neighboring nuclei. One can set an approximate lower limit on the mass excess by assuming that the log ft value for the transition to the 427 keV state is unlikely to be less than 4.5, the smallest found in a survey of 134 transitions in the decays of $^{60-63}$Zn, $^{64-68}$Ga, and $^{66-69}$Ge. This leads to $\Delta M(^{64}\text{Ge}) \geq -54.5$ MeV and, correspondingly, an alpha-separation energy $S_\alpha \leq 2.7$ MeV.

This limiting value of S_α for ^{64}Ge is only 0.5 MeV greater than that assumed in the calculations of ATW; its use would cause only minor changes in the predicted abundances.[16] Thus it appears that an (α,γ) capture chain proceeding along the N=Z line cannot synthesize the observed abundance of mass 64.

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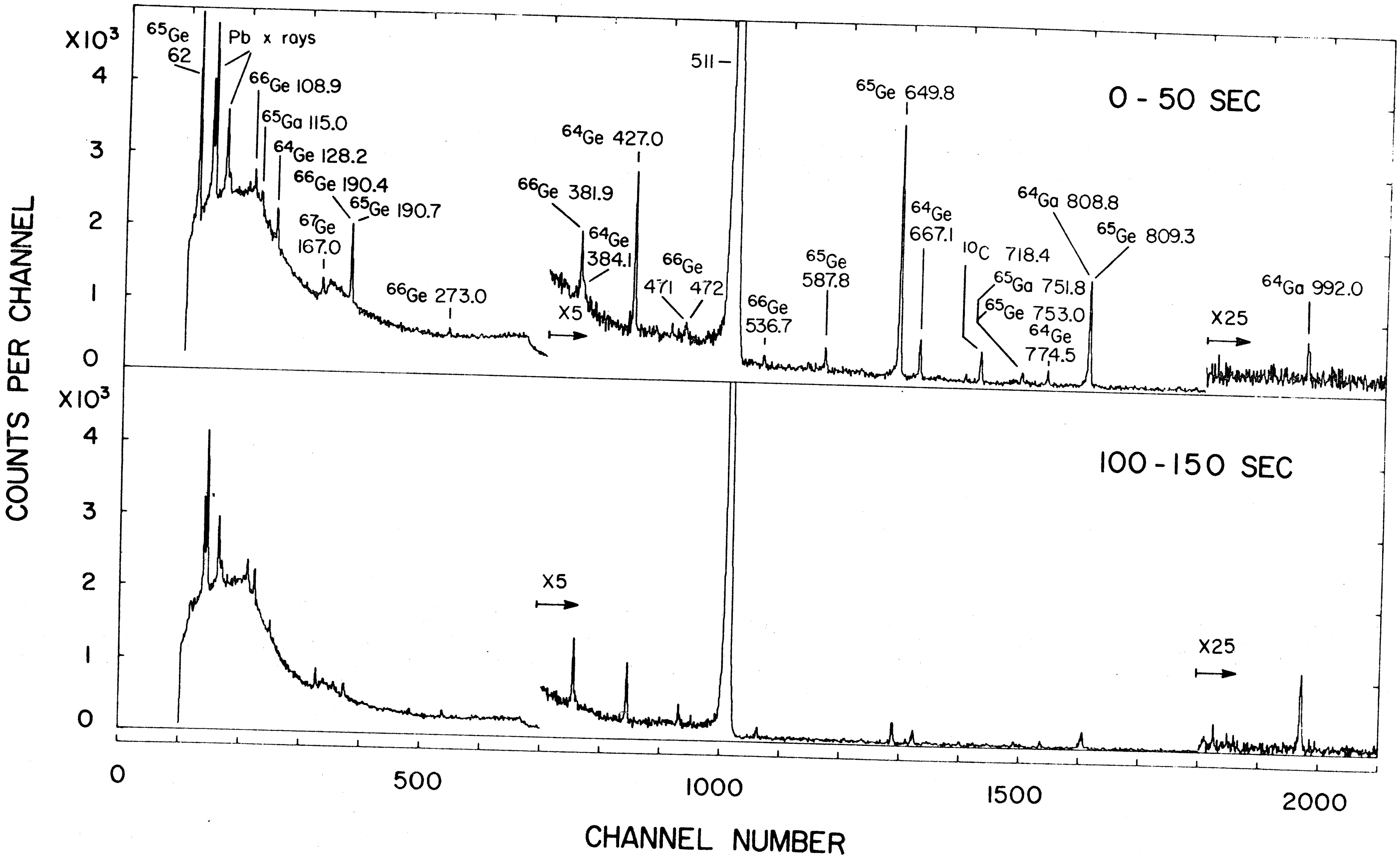
16. In a quasi-equilibrium dominated by an (α,γ) capture chain, the final abundance of ^{64}Ge is approximately proportional to $\exp(S_\alpha/kT)$, where T is the temperature at freeze-out. Assuming $T=3\times10^9$ °K, the discrepancy in the production of mass 64 could not be removed with an $S_\alpha < 3.5$ MeV. A log ft <3.9 would be implied if $S_\alpha > 3.5$ MeV.

FIGURE CAPTIONS

Fig. 1 Low-energy portions of γ-ray spectra accumulated at two different times after the chemical separation of germanium. The rapid decay of ^{65}Ge ($t_{1/2}$=30 s) and the slower decay of the new isotope ^{64}Ge ($t_{1/2}$=62 s) are apparent. The growth of the 115 keV line from ^{65}Ga and the 992 keV line from ^{64}Ga, the daughter activities, can also be seen.

Fig. 2 The upper graph shows the decay of the 427 keV γ ray from ^{64}Ge. The straight line represents the adopted half-life, 62.3 sec, least-squares fitted for intensity. The lower graph shows the growth and decay of the 992 keV line from the daughter activity ^{64}Ga. The solid curve is a calculation assuming the measured half-lives of ^{64}Ge and ^{64}Ga, least-squares fitted for the initial activities of the two isotopes. The initial activity of ^{64}Ga found in this way is, within error, zero; thus essentially all the observed ^{64}Ga results from ^{64}Ge decay.

Fig. 3 Decay scheme for ^{64}Ge. The notation and conventions of "Nuclear Data Sheets" have been adopted. The log ft values have been calculated assuming the mass excess for ^{64}Ge derived by Garvey *et al.*[2] No direct measurement of the mass excess has been made.



X10³
4
3
2
1
0
X10³
4
3
2
1
0
COUNTS PER CHANNEL
0
500
1000
1500
2000
CHANNEL NUMBER
0 - 50 SEC
100 - 150 SEC
^{65}Ge 62
Pb x rays
^{66}Ge 108.9
^{65}Ga 115.0
^{64}Ge 128.2
^{66}Ge 190.4
^{65}Ge 190.7
^{67}Ge 167.0
^{66}Ge 273.0
^{66}Ge 381.9
^{64}Ge 384.1
^{64}Ge 427.0
^{66}Ge 471 472
511
^{66}Ge 536.7
^{65}Ge 587.8
^{65}Ge 649.8
^{64}Ge 667.1
^{10}C 718.4
^{65}Ga 751.8
^{65}Ge 753.0
^{64}Ge 774.5
^{64}Ga 808.8
^{65}Ge 809.3
^{64}Ga 992.0
X5
X25
X5
X25

FIG 1

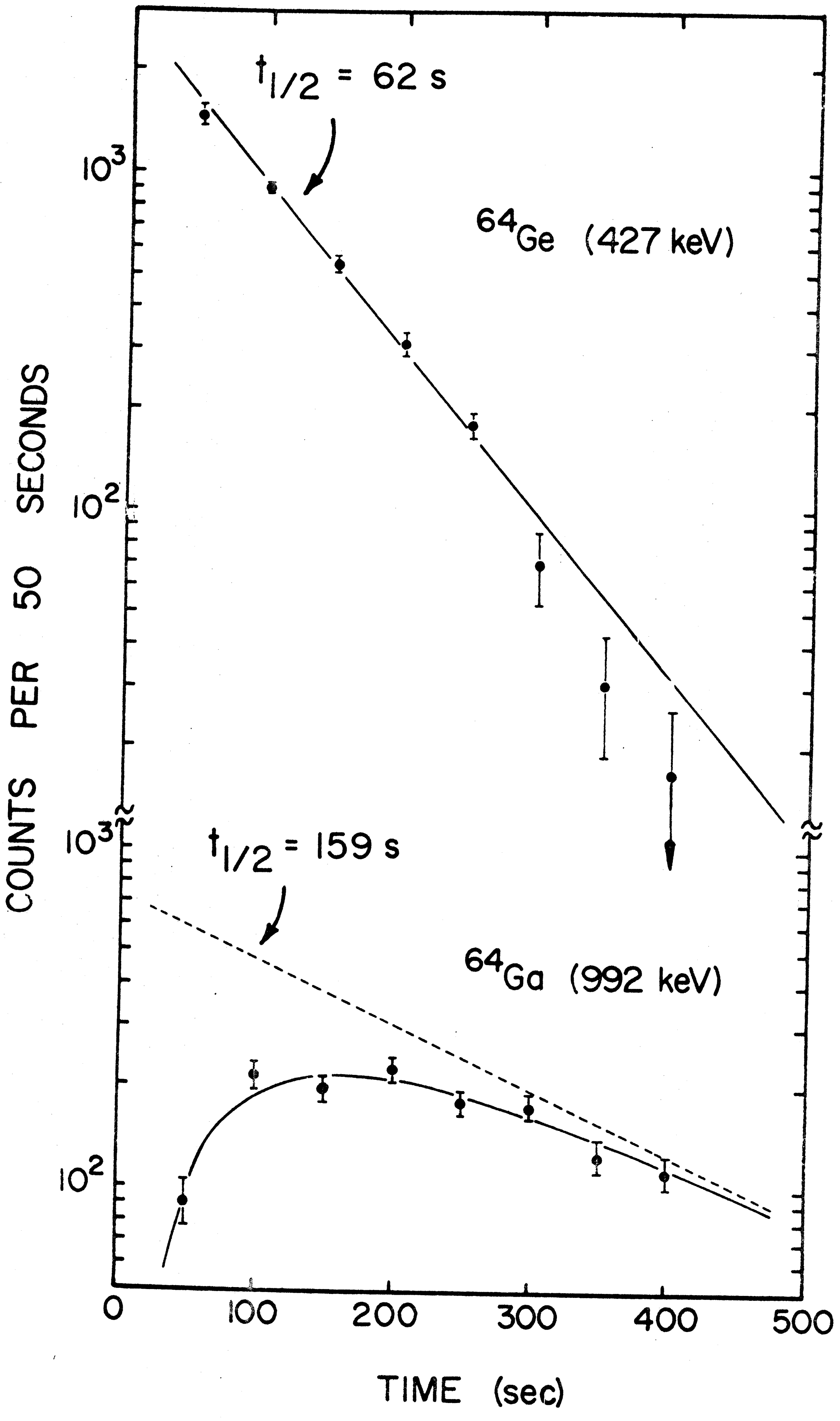

$t_{1/2}$ = 62 s
^{64}Ge (427 keV)
$t_{1/2}$ = 159 s
^{64}Ga (992 keV)
COUNTS PER 50 SECONDS
10^3
10^2
10^3
10^2
0
100
200
300
400
500
TIME (sec)

FIG. 2

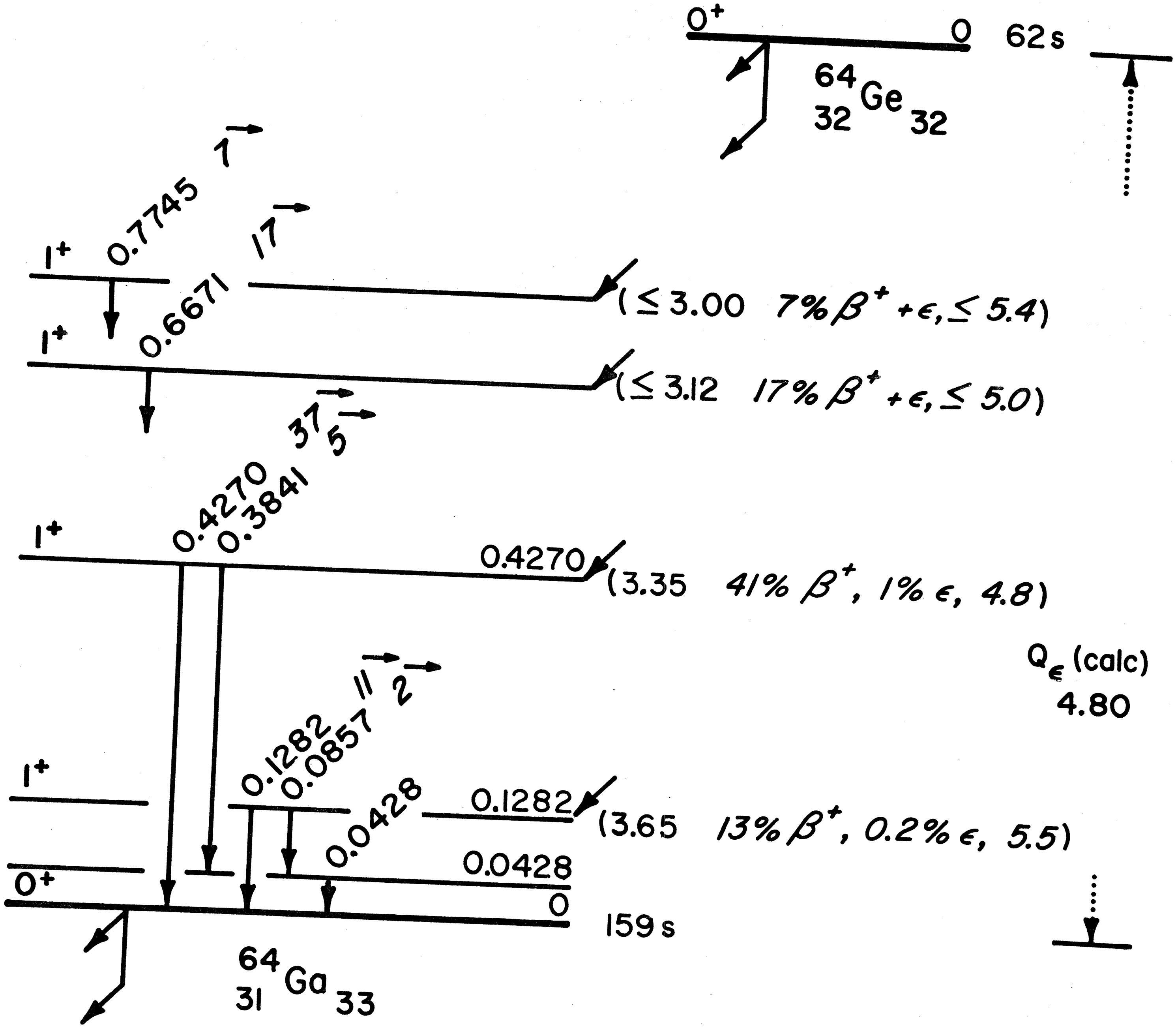

0+
0
62s
$^{64}_{32}Ge_{32}$
1+
0.7745
7
17
0.6671
1+
(≤ 3.00 7% β^+ +ε, ≤ 5.4)
(≤ 3.12 17% β^+ +ε, ≤ 5.0)
0.4270
0.3841
37
5
1+
0.4270
(3.35 41% β^+, 1% ε, 4.8)
Q_ϵ (calc)
4.80
1+
0.1282
0.0857
11
2
0.0428
0.1282
(3.65 13% β^+, 0.2% ε, 5.5)
0.0428
0+
0
159 s
$^{64}_{31}Ga_{33}$

FIG. 3