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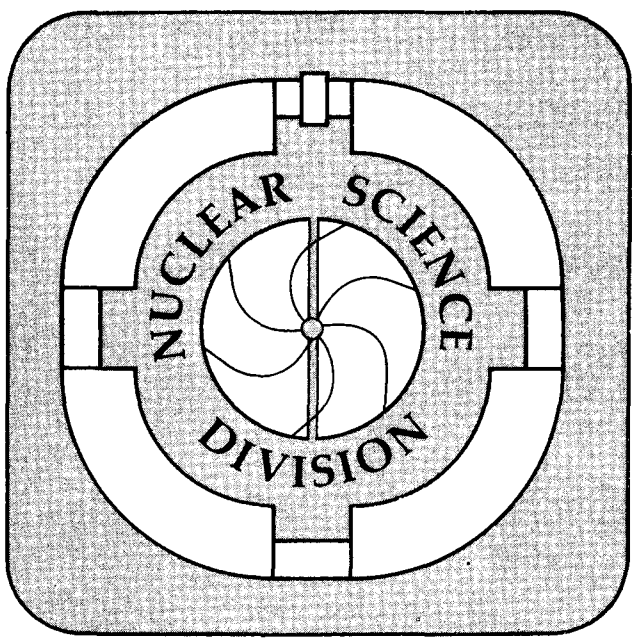

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First In-Beam γ–Ray Study of ^{67}As

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ABSTRACT

Excited states of the neutron-deficient nucleus ^{67}As were populated using the ^{40}Ca(^{32}S,αp)^{67}As and the ^{40}Ca(^{33}S,αpn)^{67}As reactions at bombarding energies between 95 and 110 MeV. We present a tentative level scheme for ^{67}As, derived from γ–γ coincidence studies in conjunction with measurement of evaporated charged particles and neutrons.

INTRODUCTION

Nuclei with N~Z and 70<A<80 show a variety of interesting structural features, including strong ground state deformations and rapid variation of shape as a function of both spin and particle number. These properties arise from competition between gaps in the oblate Nilsson level sequence at nucleon numbers 34 and 36 and a prolate shell gap at nucleon number 38. Potential energy surface calculations, employing the Strutinsky shell correction method with both deformed Woods-Saxon[1] and folded-Yukawa[2] potentials, successfully describe the experimentally established properties of this region, including the shape coexistence observed in the light Se and Kr isotopes[3-4] and the large prolate ground state deformations found in the light Sr isotopes ($\beta_2 \approx 0.3$).[5] These calculations also predict oblate deformation for the N~Z Se isotopes. This prediction was recently confirmed by Wiosna *et al* in an in-beam γ-ray study of ^{69}Se [6]. The authors extracted the sign of the quadrupole moment of ^{69}Se by measuring the E2/M1 mixing ratios of the transitions feeding its $g_{9/2}$ (neutron) positive parity band.

In-beam γ-ray studies of nuclei in this A-region require novel experimental techniques, as they are produced with cross sections ranging from a few percent to

fractions of a percent of the total fusion cross section. One powerful method for studying the structure of such exotic nuclei involves use of large arrays of Compton-suppressed Ge detectors in conjunction with neutron and charged particle counters for enhancement of weakly populated channels. We employed this technique in an experiment which yielded the first evidence for observation of the structure of the neutron-deficient nucleus ^{67}As, a nuclide on the periphery of the highly deformed 70<A<80,N~Z region. An in-beam γ-ray measurement of ^{67}As should provide the opportunity to study whether the deformation observed in the N~Z Se isotopes also extends to lighter N~Z nuclei.

EXPERIMENTAL METHOD

These measurements employed ~3pnA beams of ^{32}S and ^{33}S, accelerated to 95-110 MeV by the Lawrence Berkeley Laboratory 88-Inch Cyclotron facility. The targets consisted of 1mg/cm^2 natural Ca evaporated onto 50 mg/cm^2 Pb foils, which stopped recoils while permitting detection of evaporated charged particles in a 250μm, 300mm^2 Si counter placed 5mm behind the target assembly. This single counter provided crude discrimination between protons and alpha particles on the basis of their different ranges in Si. Alpha particles tended to lose their full (15-25 MeV) laboratory energies in the detector, whereas the 10-12 MeV protons deposited only part of their energies, typically 3-5 MeV. The target assembly and Si counter were located inside the BGO central ball of the 21-fold HERA anti-Compton spectrometer. For these measurements, the 0° HERA Ge was replaced with an 80 cm^2 x 10 cm liquid scintillation counter, which operated with a roughly 1.5% neutron detection efficiency in a pulse shape discrimination mode.

By placing gates on the alpha region of the charged particle spectrum described above and on the neutron peak in the scintillation counter TAC spectrum, it was possible to enhance alpha and neutron-coincident lines by a factor of ~5-8 over γ rays from the dominant 3p and 4p evaporation channels. Comparing figures 1(a) and 1(b), for example, shows the enhancement of the 734-keV line from ^{67}Ge, the α2p evaporation product from the ^{33}S bombardment, over the 321-keV γ-ray from ^{70}As, the 3p channel. A comparison of figures 1(a) and 1(c), on the other hand, shows the roughly 8-fold enhancement of the 945-keV line from the 2pn channel, ^{70}Se, over the same ^{70}As γ-ray.

A group of previously unidentified γ-rays were enhanced in the α–γ–γ sum spectrum in the ^{32}S bombardment and in both the α–γ–γ and n–γ–γ sum spectra in the ^{33}S bombardment . In each case, these peaks showed excitation functions consistent with two

or three particle evaporation channels. An analysis of the spectrum of charged particles coincident with these γ-rays showed that they corresponded to evaporation of one alpha particle and one proton. Since the αp channels from ^{32}S on the ^{24}Mg, ^{16}O and ^{12}C contaminants in the ^{40}Ca target are known, and showed no coincidence with the new peaks, we were able to rule them out. We hence assigned the new γ rays to ^{67}As, produced as the αp channel from $^{32}S + ^{40}Ca$ and the αpn channel from $^{33}S + ^{40}Ca$.

The ^{67}As level scheme shown in figure 2 was established on the basis of γ–γ, α–γ–γ and n-γ–γ coincidences, intensity balance and energy summing relationships. A spectrum of γ-rays in coincidence with the low-lying 697 keV transition, taken from the ^{33}S bombardment, is shown in figure 3. Comparing the coincidence analyses from each bombardment provided a rigorous cross-check on the assignment to ^{67}As of several peaks which were either too weak to be clearly observed in the γ–γ sum spectra or which formed doublets with intense lines from contaminants.

DISCUSSION

The properties of the odd-A, proton-rich Ge,As and Se isotopes are determined by the $g_{9/2}$ single particle orbital and by the closely spaced $p_{1/2}$, $p_{3/2}$ and $f_{5/2}$ orbitals which dominate the low-lying neutron or proton structure of these nuclei. The first positive-parity (neutron or proton) states in this region tend to be $9/2^+$, and these states decay via isomeric stretched M2 transitions to low-lying $5/2^-$ states. These $9/2^+$ states typically form the bandhead for a sequence of positive-parity levels connected by stretched E2 transitions. Such band structures are usually interpreted as either the coupling of a $g_{9/2}$ nucleon to a vibrating even-even core or as decoupled bands built on the rotation of a deformed even-even core.

Murphy *et al* [7] have tentatively assigned a ground state J^π of 5/2- to ^{67}As based both on a ß-decay study which yielded log(ft) values to known states in ^{67}Ge and on systematic arguments about the strength of the proton pairing force as a function of neutron number in the odd-A As isotopes. The 697 keV transition feeding the ground state has an angular distribution sharply peaked at 90° relative to the beam direction, indicating a strong dipole character. If the $5/2^-$ ground state J^π assignment is correct, this permits a tentative assignment of J = 7/2 to the 697-keV state.

The 1423-keV level may be considered as a candidate for the $9/2^+$ state. This level is fed by two parallel decay cascades, the strongest of which, the 1358→1228→943 sequence, has level spacings similar to the $g_{9/2}$ band structures seen in neighboring nuclei (see figure 4). If the 1423-keV state has $J^\pi = 9/2^+$, then its decay to the $5/2^-$ ground state should have an angular distribution characteristic of a stretched quadrupole transition, as should the 943, 1228 and 1358-keV lines. The 1423 and 1358-keV γ rays appear cleanly in the raw γ–γ total spectrum, permitting extraction of their angular distributions, while the 943 and 1228-keV lines form doublets with contaminant transitions. Angular distributions of the 1423 and 1358-keV transitions show sharp minima at 90°, consistent with a strongly quadrupole character. Multipolarities for the 943 and 1228 were deduced from directional correlation (DCO) ratios using a simple procedure described by Stephens[8]. Gating on known stretched E2 transitions in ^{66}Ge and projecting out coincident stretched E2 and E1 lines, this procedure yields DCO values of roughly 1.1 and 0.5 for stretched quadrupoles and dipoles, respectively. Gating on each line in the 1358→1228→943 sequence and projecting out the other two transitions in the cascade yields DCO ratios within experimental error of 1.1, while ratios for coincident transitions not in this sequence show large variations. This analysis suggests that the states at 1423, 2365, 3593 and 4951-keV form the $g_{9/2}$ positive-parity band, with spins of $9/2^+$, $13/2^+$, $17/2^+$ and $21/2^+$ respectively. A more detailed angular correlation procedure is now underway to establish spins for the weaker parallel band (the technique employed above to find stretched quadrupole γ rays is ineffective for studying the mostly mixed E2/M1 transitions connecting members of the negative-parity bands in nuclei in this region).

The proposed structure of ^{67}As displayed in figure 4 appears consistent with the systematics in this region. The energy of the $9/2^+ \rightarrow 5/2^-$ transition fits in nicely with the smooth trends seen in the odd-A As isotopes and the odd-Z, N=34 isotones. Unlike ^{69}Se, the next $T_z = 1/2$ nucleus, the proposed $g_{9/2}$ band in ^{67}As shows no clear sign of deformation. In fact, the energies of the ^{67}As positive-parity states correspond rather nicely to those in ^{67}Ge and to the vibrational ground state band in ^{66}Ge, the closest known even-even core(see figure 5). This would suggest that the odd proton in ^{67}As forms the positive-parity band by coupling to the core vibrations of the adjacent ^{66}Ge. Thus, it seems that the region of deformation seen to extend down to the lightest Se isotopes disappears in the odd N~Z As isotopes.

In conclusion, we have observed the decays of excited states of the neutron-deficient nucleus ^{67}As, produced with 2% and 3% of the total reaction cross sections in the

^{32}S and ^{33}S bombardments of ^{40}Ca respectively. Using angular distributions and a simple angular correlation procedure we have tentatively identified the $g_{9/2}$ positive-parity band in ^{67}As and found it to be consistent with the couplings of the odd $g_{9/2}$ proton to vibrations of the lighter even-even ^{66}Ge core.

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FOOTNOTES

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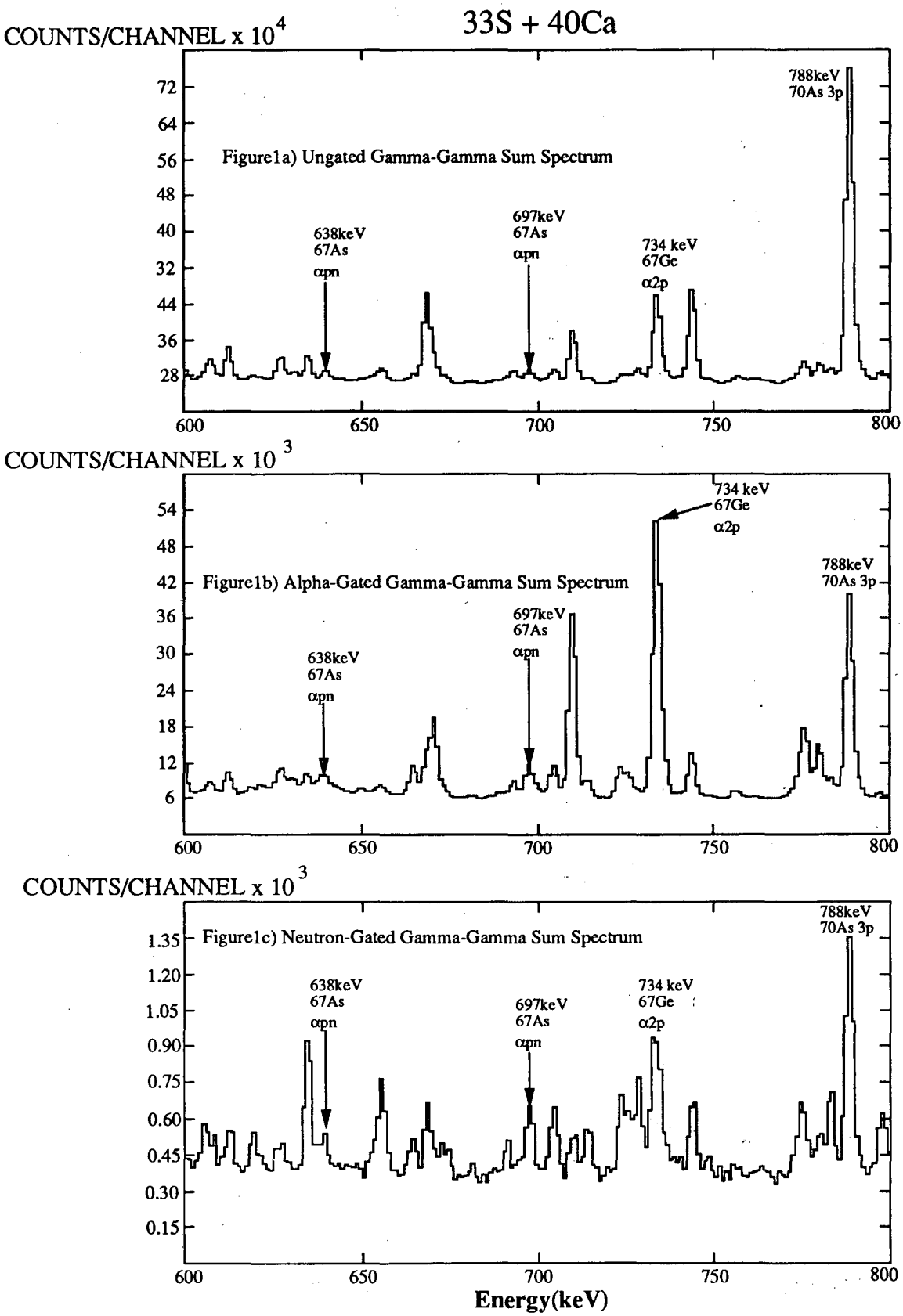
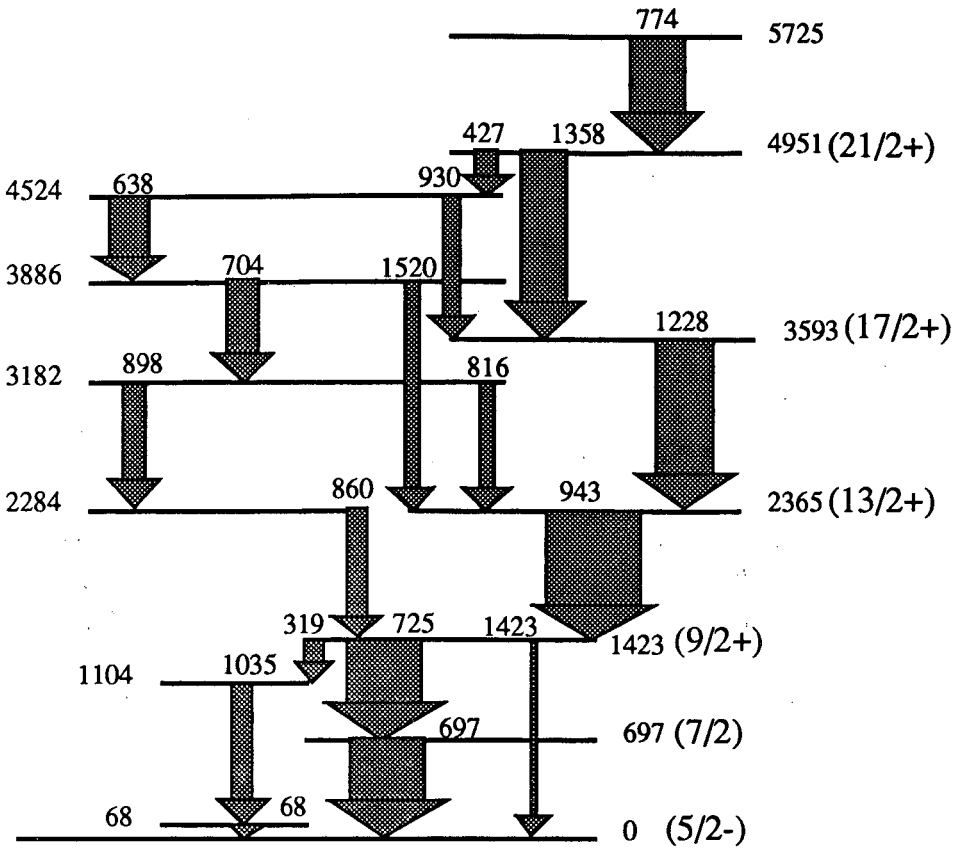


Figure 1) Example of channel enhancement using charged particle and neutron counters in 33S bombardment. 638 and 697 keV peaks belong to 67As, the αpn evaporation channel.



Figure(2) Proposed Preliminary Level Scheme for ^{67}As

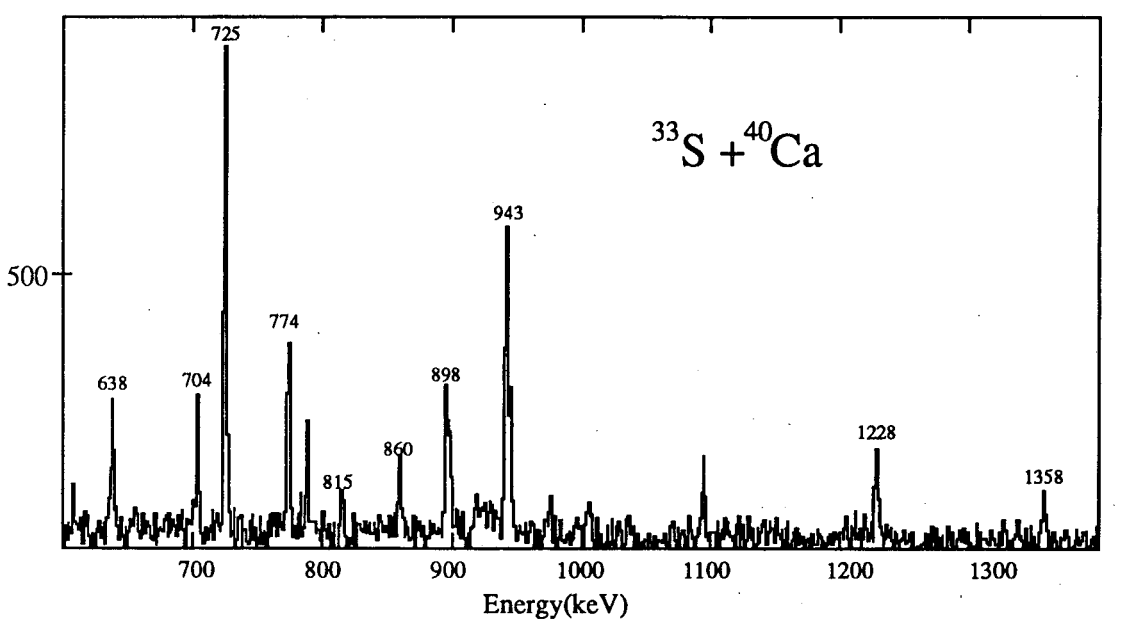


Figure (3) Spectrum of gamma rays in coincidence with 697- keV transition. The unlabeled peaks are contaminants from 70As and 69As.

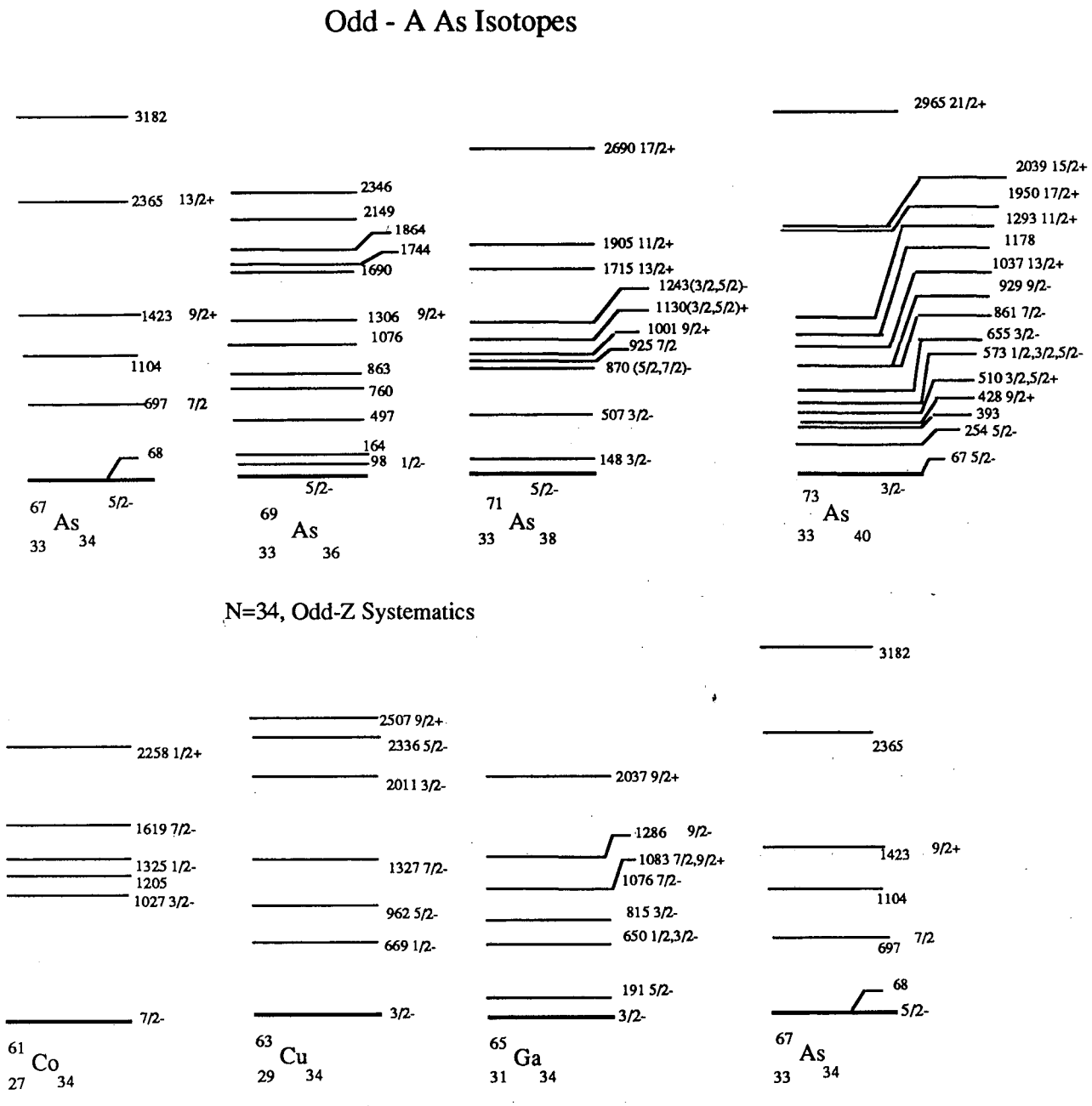


Figure 4. Systematic trends in odd-A As isotopes and odd-Z N=34 isotones; The energy of the 9/2+ state increases smoothly as a function of decreasing neutron number in the odd-A isotopes, and decreases as a function of increasing Z in the odd-Z isotones.

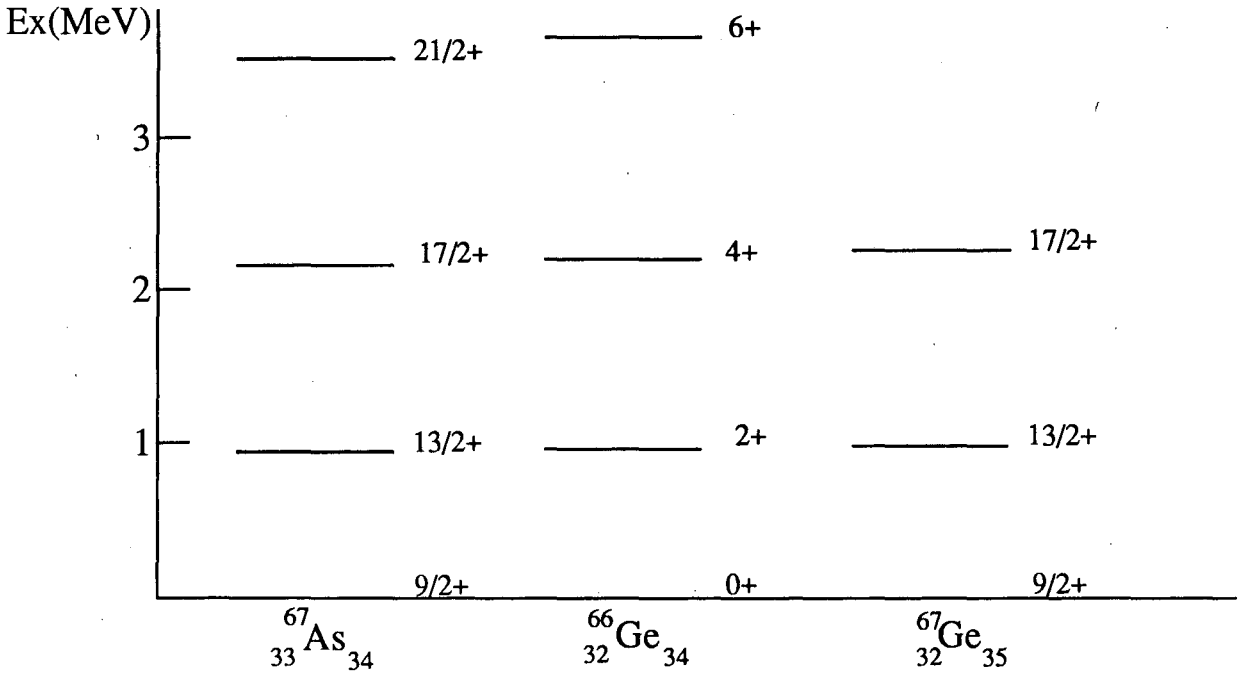


Figure 5 Comparison of energies of members of positive parity bands in 67As and 67Ge to ground state band of 66Ge. Energies of 9/2+ states in 67As and 67Ge are shifted downwards so as to make them equal to the 66Ge ground state

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