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Decay of Ar^{41}

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A weak gamma ray has been found in the decay of Ar^{41} to K^{41}. The energy of the gamma ray is 1.664 ± 0.007 MeV; and its intensity, relative to that of the strong 1.293-MeV gamma ray, is $(5\pm2)\times10^{-4}$. It is concluded from the results of coincidence measurements that this gamma ray is the result of a beta-ray branch from Ar^{41} leading to an excited state in K^{41} at 1.664 MeV. The associated log *ft* value is found to be 7.7 ± 0.3. The spin and parity of the 1.664-MeV state in K^{41} are most probably $\frac{5}{2}^+$ or $\frac{7}{2}^+$.

INTRODUCTION

IT has been well established[1–6] that the radioactive decay of Ar^{41} leads primarily to an energy level in K^{41} at 1.293 MeV, with a small fraction ($\lesssim1\%$) of the distintegrations populating the ground state directly. No other beta-ray transitions from Ar^{41} have been observed. Nuclear-reaction studies,[5–7] however, have revealed several levels in K^{41} with energies which would permit their population by additional Ar^{41} beta-ray groups. The present investigation was undertaken to search for weak gamma-ray transitions associated with the beta decay of Ar^{41} to any of these levels. The observation of such transitions is expected to give information about the spins and parities of the levels involved, and thus contribute to the understanding of the nuclear structure of K^{41}.

EXPERIMENTAL PROCEDURE AND RESULTS

Samples of argon gas, sealed in polyethylene, were exposed to neutrons from the Pennsylvania State University Research Reactor. Ar^{41} was produced in the (n,γ) reaction. After exposure the gas was transferred to an aluminum or polyethylene container, and the gamma-ray spectrum was measured using a 3×3-in. cylindrical NaI scintillation spectrometer employing a conventional multichannel pulse-height analyzer. The detecting crystal was housed in a lead collimator-shield with a 1-in. diam$\times$3-in. aperture. A beta-ray shield of $\frac{1}{2}$-in. polyethylene was inserted between the source and the crystal.

A typical gamma-ray spectrum is shown in Fig. 1. This spectrum resulted from a 30-min exposure behind a 2-ft graphite thermal column. Counting was started 30 min after the end of the exposure; the counting time

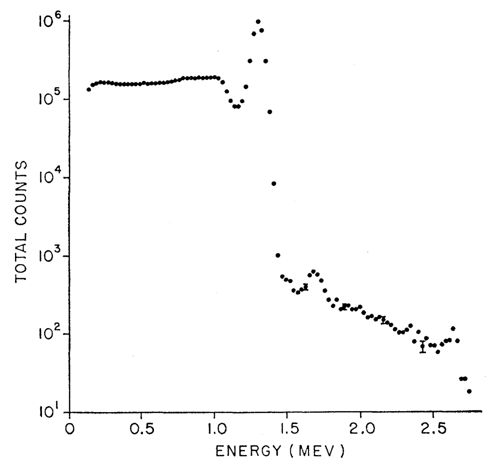

FIG. 1. Gamma-ray spectrum associated with the decay of Ar^{41} as recorded with a 3-in.$\times$3-in. NaI(Tl) scintillation spectrometer.

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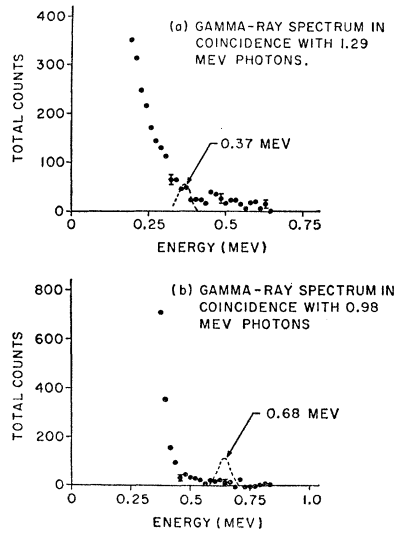

FIG. 2. Coincidence gamma-ray spectra associated with the decay of Ar^{41}: (a) Spectrum coincident with a pulse-height gate between 1.24 and 1.34 MeV. (b) Spectrum coincident with a pulse-height gate between 0.93 and 1.03 MeV.

was 100 min. In addition to the well-known gamma ray of 1.293 MeV, a higher energy gamma ray of 1.66 MeV is clearly observed in this spectrum. The continuum above 1.7 MeV and the peak at 2.6 MeV are attributed mainly to "pileup" of the strong 1.293-MeV gamma rays.

A series of measurements in which the conditions of exposure and counting were varied clearly indicates that the 1.66-MeV gamma ray is associated with the decay of Ar^{41}: (a) Gas samples have been prepared using argon sources of different purity; ordinary "tank" argon (99.99%) and highly purified "purgon" (99.998%, Air Products Inc.). (b) Gas samples were collected by two alternative methods; bubbling of the gas under water into a polyethylene bottle initially filled with water, and dry collection (using a vacuum system) in an initially evacuated polyethylene tube which was subsequently heat-sealed. (c) Exposures have been made both with and without the thermal column, resulting in drastically different ratios of fast and thermal neutrons. The spectra obtained in all of these measurements (a, b, and c) show substantially the same intensity ratios for the 1.66- and 1.293-MeV gamma rays. (d) Measurements in which the gas sample was prepared by substituting air for argon show no indication of the 1.66-MeV gamma ray other than that which can be attributed to argon present in the air. (e) A series of half-life measurements has been carried out, in which sources were prepared using different exposure times and allowing different decay times before starting to measure the spectrum. These measurements show the relative intensities of the 1.66- and 1.293-MeV gamma rays to be the same within at least a factor of two when measured over a range of decay times of 1400 min—corresponding to about 13 Ar^{41} half lives. These results indicate the half lives of the two gamma rays to be indentical within at least 5%.

From the results described above it is concluded that the high-energy gamma ray shown in Fig. 1 may be unambiguously assigned to the decay of Ar^{41}. The combined results of several measurements give an energy value for this gamma ray of 1.664 ± 0.007 MeV and an intensity, relative to that of the 1.293-MeV gamma ray, of $(5\pm2)\times10^{-4}$.

In order to determine whether there are any cascade transitions in parallel with the 1.664-MeV transition, and also whether this transition results from beta decay to a 1.664-MeV level or is part of a cascade from a higher energy level, a series of coincidence measurements was performed. In these measurements two detectors were placed face to face with a 1-in. spacing between them, the source being located midway between the detectors. A $\frac{1}{2}$-in. lead antibackscattering shield was employed when appropriate. Pulses from one detector were directed to the input of the multichannel analyzer. Pulses from the other, after passing through a single-channel analyzer (SCA) with a "window" of adjustable base and width, were used to gate the multichannel analyzer so that only coincident events were recorded.

In searching for cascade transitions summing to 1.664 MeV several individual coincidence measurements were made. The SCA window, usually with a width of 0.1 MeV, was set at a sufficient variety of energies to insure the detection of coincidences involving a single gamma ray with an energy in the range 0.05 to 1.61 MeV and intensity comparable to that of the 1.664-MeV gamma ray. Special attention was given to the search for gamma-ray pairs containing a member with an energy corresponding to any of the reported[5,7] K^{41} levels (0.6, 0.72, 0.98, 1.293, 1.559, 1.580, 1.6 MeV) between 0 and 1.664 MeV. With the SCA window set to encompass the 1.664-MeV gamma ray, coincident gamma rays with energies between 0.05 and 0.8 MeV, corresponding to a cascade containing the 1.664-MeV transition, were sought.

Examples of the results of these measurements are shown in Figs. 2(a) and 2(b). Each of these represents a composite of four 100-min counts, with accidental coincidences subtracted.

Figure 2(a) shows the coincidence spectrum obtained with the SCA window adjusted to pass pulses corresponding to energies between 1.24 and 1.34 MeV. A cascade from a 1.664-MeV level via the 1.293-MeV level would be expected to show a peak at 0.37-MeV and, if of the same intensity as that of the 1.664-MeV gamma ray, would give a spectral peak as shown by the dotted line. The coincidence spectrum is complicated in this energy region by a continuum upon which the 0.37-MeV peak would be superimposed. Auxiliary measurements with a source of P^{32}, a pure beta emitter, indicate that this continuum is of a magnitude to be expected from coincidences between the 1.293-MeV gamma ray and internal and external bremsstrahlung associated with the beta-ray group which is in coincidence with this gamma ray. The presence of the continuum makes it difficult to place a very low limit on the possible intensity of an 0.37- to 1.293-MeV cascade. It is found, however, that the subtraction from the spectrum of a peak of $\frac{1}{2}$ the strength of that shown by the dotted line results in a clearly anomalous dip. We infer from this that there is no such cascade with an intensity greater than 50% of the intensity of the 1.664-MeV gamma ray.

The other coincidence measurements involving known levels in K^{41} are not subject to the above-mentioned difficulty. A representative example is shown in Fig. 2(b). This is the result of a measurement in which the SCA window is adjusted to pass pulses corresponding to energies between 0.93 and 1.03 MeV. The sharp rise at low energies is due to scattering of 1.293-MeV gamma rays between the two detectors. A cascade from a 1.664-MeV level via the known 0.98-MeV level, having an intensity the same as that of the 1.664-MeV gamma ray, would result in a spectral peak indicated by the dotted line in Fig. 2(b). It is quite clear that any such cascade is of appreciably lower intensity than that of the 1.664-MeV gamma ray. Similar results have been obtained in looking for other cascades; including a cascade involving a 1.664-MeV gamma ray as one member and a gamma ray between 0.05 and 0.8 MeV as the other.

It is concluded from the measurements described above that the 1.664-MeV gamma ray results primarily from Ar^{41} beta decay to a K^{41} level of this energy; and furthermore that this level decays primarily by means of a transition directly to the K^{41} ground state. From the measured relative intensities of the 1.664- and 1.293-MeV gamma rays, together with previously determined information[5] concerning the decay of Ar^{41}, it is possible to calculate the log *ft* value associated with the beta-ray transition. The resulting log *ft* value is 7.7 ± 0.3.

CONCLUSIONS

It has been found that the beta decay of Ar^{41} leads, with a probability of about 5×10^{-4}, to the population of an excited state in K^{41} at 1.664 ± 0.007 MeV. The beta-ray end-point energy may be inferred[3] to be 0.83 MeV, and the associated log *ft* value 7.7 ± 0.3. The excited state decays to the ground state primarily by way of a single gamma-ray transition.

It is probable that the K^{41} level involved is the same as that previously reported[5] at 1.675 MeV, although some evidence[8] for a multiplicity of levels in this region makes this association uncertain. The *ft* value associated with the beta-ray transition is most probably indicative of a first-forbidden nonunique transition. If it is assumed that the beta-ray transition is of this type (this assumption necessarily being open to doubt in view of the wide range of *ft* values associated with a given transition type), then the $\frac{7}{2}^-$ assignment[6] to the Ar^{41} ground state would require a spin and parity of $\frac{5}{2}^+$, $\frac{7}{2}^+$, or $\frac{9}{2}^+$ for the K^{41} excited state. This is indeed consistent with the assignment[5] of $\frac{5}{2}^+$ to $11/2^+$ which has been made for the 1.675-MeV state on the basis of capture gamma-ray measurements. Assuming[6] that the 1.293-MeV state in K^{41} has a spin and parity of $\frac{7}{2}^-$, the $\frac{9}{2}^+$ assignment to the 1.664-MeV state would presumably be ruled out in view of the lack of a competitive transition between these two states: this transition would be $E1$, whereas the transition to the ground state $(\frac{3}{2}^+)^6$ would be M3. It can thus be concluded that the spin and parity of the 1.664-MeV state in K^{41} are most probably either $\frac{5}{2}^+$ or $\frac{7}{2}^+$.

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