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A PRECISE DETERMINATION OF THE EXCITATION ENERGY
OF THE LOWEST $T=3/2$ STATE IN ^{35}Ar

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ABSTRACT

The excitation energy of the lowest $T=3/2$ state in ^{35}Ar has been determined to be 5572.71 ± 0.17 keV from the measured energies of β -delayed γ -rays following the decay of ^{35}K ($t_{1/2} = 190 \pm 30$ ms). The coefficient of a possible cubic term in the isobaric multiplet mass equation for the $A = 35$ quartet is -4.3 ± 3.6 keV.

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The quadratic isobaric multiplet mass equation (IMME) is known to reproduce the mass excesses of $T = 2$ and $T = 3/2$ multiplets with remarkable accuracy. This equation, which results from first order perturbation theory under the assumption that two-body forces are responsible for the charge dependence in nuclei, predicts that the mass excesses within a multiplet should be described by the equation

$$M(A, T, T_z) = a(A, T) + b(A, T)T_z + c(A, T)T_z^2 \quad (1)$$

Its success for multiplets with more than three members simply demonstrates how small the effects of charge-dependent mixing usually are, since the coefficients of higher order terms, $dT_z^3 + eT_z^4$, relate through second order perturbation theory to off-diagonal matrix elements of the charge-dependent part of the total Hamiltonian. The measurement of a non-zero d or e coefficient for any multiplet would be a clear indication of charge-dependent mixing or possibly of more complex phenomena.

The success of the quadratic IMME is especially apparent among the $T = 3/2$ isobaric quartets¹⁾ where more than 20 multiplets have by now been completed. Only in one case, the ground state $A = 9$ quartet, has a significant non-zero d coefficient been found. This quartet is also the most precisely measured one, which stresses the need for precision in searching for deviations from the quadratic IMME.

The only uncompleted ground state quartet among sd shell nuclei is the one at $A = 35$, where the lowest $T = 3/2$ state in ^{35}Ar has so far not been unambiguously identified. A level at an excitation energy of 5537 ± 25 keV, populated in the $^{33}\text{S}(^3\text{He}, n)^{35}\text{Ar}$ reaction, has been proposed by Davidson et al²⁾ as a candidate for the $T = 3/2$ state, but the peak observed in their time-of-flight neutron spectrum was very weak while the background in the region of

interest was high and included the tail from a nearby contaminant peak. A separate attempt to observe this proposed state in the $^{35}\text{Cl}(^3\text{He},t)^{35}\text{Ar}$ reaction was not successful³⁾. Furthermore, if the proposed 5537 keV level is accepted, it leads to a d coefficient of -22 ± 13 keV, which would be the largest deviation from 0 found so far. A reliable test of the IMME for this quartet thus requires a much better identification of the $T = 3/2$ state in ^{35}Ar .

We wish to report here a precise measurement of the lowest $T = 3/2$ state in ^{35}Ar , unambiguously identified through its population in the beta decay of ^{35}K . A more comprehensive description of this first observation of the decay of ^{35}K will be published in a parallel paper⁴⁾.

Potassium isotopes were produced by spallation reactions in a 13.6 g/cm² target of ScC_2 bombarded by 1.7 μA of 600 MeV protons from the CERN Synchrocyclotron. The evaporation residues diffused out of the hot (2000°C) target and reached a surface ionization source where the potassium atoms were selectively ionized. The potassium beam extracted from the ion source was separated into its constituent masses by the ISOLDE isotope separator. A beam of ~ 5000 atoms/s corresponding to mass 35 was transported to a low background counting area and intercepted by a thin mylar foil. A 109 cm³ $\text{Ge}(\text{Li})$ detector situated behind the foil observed gamma rays emitted from the collected activity.

In all, 19 gamma rays up to 5 MeV were detected and assigned⁴⁾ to the γ -decay of levels in ^{35}Ar , the β -decay daughter of ^{35}K . Their measured decay time indicated a half-life of 190 ± 30 ms for ^{35}K . From the relative γ -ray intensities, it was possible to deduce the relative intensities of all β -transitions from ^{35}K except that which populates the ^{35}Ar ground state. If it is assumed that the ground state transition has a $\log ft$ of 5.07 (a value derived⁴⁾ from the mirror $^{35}\text{S} \rightarrow ^{35}\text{Cl}$ decay), then $\log ft$ values can be assigned directly

to the excited state transitions as well. As a result, one of these transitions - to a state at 5.57 MeV - showed a $\log ft$ value of 3.34 ± 0.10 . Since it is the only transition observed with a $\log ft$ value less than 4.3, this superallowed decay unambiguously identifies the ^{35}Ar state as the $T = 3/2$ analogue to the ground state of ^{35}K .

The analogue state was determined to be deexcited mainly by a cascade of two gamma rays, one at 2.59 MeV, the other at 2.98 MeV. In order to determine precisely the excitation energy of this state a second experiment was performed in which the beta-delayed gamma rays from ^{35}K were recorded simultaneously with gamma rays from a ^{56}Co source, which provides suitable calibration lines. Part of the γ -ray spectrum obtained in this way is shown in Fig. 1.

The energy of the first gamma ray in the cascade was precisely determined relative to the 2598.460 ± 0.010 keV gamma ray from $^{56}\text{Co}^{5)}$, since their energy difference is only 9 keV. The second gamma ray in the cascade, however, has no strong counterpart in the ^{56}Co γ -ray spectrum. Consequently the energy of this gamma ray was deduced from the energy of its single escape peak determined relative to the ^{56}Co gamma ray already mentioned, and from the energy of its double escape peak determined relative to the 2015.179 ± 0.011 and 2034.759 ± 0.011 keV gamma rays from $^{56}\text{Co}^{5)}$ (Fig. 1). The final results obtained for the energies of the two ^{35}K gamma rays of interest were 2589.80 ± 0.10 and 2982.68 ± 0.13 keV respectively. After correcting the γ -ray energies for nuclear recoil, the excitation energy of the analogue state was deduced to be 5572.71 ± 0.17 keV. This result is significantly different from the previously proposed value 5537 ± 25 keV²⁾, a fact that may be accounted for by the difficult experimental conditions prevailing in the earlier experiment.

The $A = 35$ isobaric quartet has thus been completed and its properties are given in Table 1. A good fit to the experimental data is obtained with the quadratic form of the IMME, resulting in a χ^2 of 1.4. The coefficients derived for a cubic IMME are $a = -20469.4 \pm 1.9$, $b = -5882.7 \pm 3.0$, $c = 205.2 \pm 5.1$ and $d = -4.3 \pm 3.6$ keV. Evidently the d coefficient does not deviate significantly from zero, although it does suggest the need for reducing the experimental uncertainties on the masses of other members of the $A = 35$ quartet. In particular, one may point out that a recent remeasurement⁸⁾ of the excitation energy of the $T = 3/2$ state in ^{35}Cl differed from the old value⁷⁾ by 5 keV. Such a big difference has a substantial effect on the d coefficient, and it would therefore be valuable to obtain a third independent measurement in ^{35}Cl before drawing final conclusions about the $A = 35$ coefficients.

The present result is not inconsistent with the main body of experimental data on isospin quartets since it agrees with the quadratic IMME. Notwithstanding the apparent close proximity of $T = 1/2$ states with possibly the same spin³⁾, there seems to be little effect on the $T = 3/2$ states as a result of isospin mixing.

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FIGURE CAPTIONS

Fig. 1 Parts of a gamma ray singles spectrum from the decays of ^{35}K and ^{56}Co . A simplified decay scheme for ^{35}K is shown in the upper left corner. SE and DE indicates single and double escape peaks, respectively. The full width half maximum for peaks at 2.5 MeV is 2.8 keV.

Table 1. Properties of $T = 3/2$ states in the $A = 35$ quartet.

Nuclide	T_z	Mass Excess (keV)	Ex (keV)
^{35}S	3/2	$-28\,846.27 \pm 0.21^{\text{a}}$	0
^{35}Cl	1/2	$-23\,360 \pm 2^{\text{a}}$	$5654 \pm 2^{\text{b}}$
^{35}Ar	-1/2	$-17\,476.2 \pm 1.6^{\text{c}}$	$5572.71 \pm 0.17^{\text{d}}$
^{35}K	-3/2	$-11\,169 \pm 20^{\text{e}}$	0

a The ground state mass excess was taken from The 1977 Mass Evaluation⁶⁾.

b Mean of the values reported in ref. 7 and ref. 8.

c The ground state mass excess was taken from ref. 9.

d This work

e Ref. 1