Lifetime of the First Excited State of K^{40}†

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The first excited state of K^{40} at 29.4 kev has been produced by using the reaction $A^{40}(p,n)K^{40}$. Its mean life, measured by a pulsed-beam technique, is 5.6±0.5 mμsec.

I. INTRODUCTION

THE shell model with *j-j* coupling has been very successful in regions near closed shells and, in particular, near the doubly magic nucleus Ca^{40}. Several computations employing this model have been made for K^{40}. Feenberg[1] first showed that it gave the magnetic moment of the ground state as −1.70 nm, compared to the measured value of −1.29 nm. Both Pandya[2] and Goldstein and Talmi[3] have used this model with striking success to compute the level scheme of Cl^{38} from the level scheme of K^{40}. The empirical evidence concerning K^{40} has been summarized by Way *et al.*[4] and by Endt and Braams.[5] In addition, we have recently completed an investigation[6] of the level scheme of K^{40} and obtained some new data on this nucleus.

The ground state of K^{40} is known to have spin 4, the first excited state at 29.4 kev is expected to have spin 3, and both are expected to have negative parity. The transition between these two states should therefore be predominantly magnetic dipole. We report here a measurement of the lifetime of the first excited state of K^{40}. This provides another point on which the *j-j* coupling model can be checked with experiment.

II. EQUIPMENT AND PROCEDURE

The first excited state of K^{40} was produced by proton bombardment of A^{40} in the reaction $A^{40}(p,n)K^{40}$ using the 4-Mev electrostatic accelerator at Argonne National Laboratory. The lifetime measurements were made with the equipment[6] previously used to measure the time-of-flight of neutrons from the same reaction. As before, the proton beam (with an energy of 2.55 Mev) was deflected across a slit by a 3.5-Mc/sec rf field to produce bursts of protons of 2 mμsec duration.

To discriminate against neutrons and gamma rays having other than the energy of interest, a NaI(Tl) scintillator $\frac{1}{2}$ inch in diameter and $\frac{1}{16}$ inch thick replaced the plastic scintillator used for neutron detection. Typical pulse-height spectra for gamma rays from the reaction $A^{40}(p,n)K^{40}$ are shown in an earlier paper.[6] To prevent fatigue effects from changing the gain of the photomultiplier by more than a few percent,[7] the photomultiplier voltage was adjusted so that the average anode current always was less than 0.2 μa.

The gas target consisted of a long aluminum tube with a polyethylene liner, and a thin nickel window. After passing through the gas, the proton beam was stopped near the end of the tube by a graphite slug. The shielding between target and detector was arranged so that gamma rays from a 1-cm length of the target could go directly to the detector, but gamma rays and x-rays from the window or stopping slug could not reach the detector except by scattering.

The number of scintillations of a size corresponding to a photoelectric event produced by the 29.4-kev gamma rays of K^{40} was recorded as a function of the time after the proton burst to obtain the "delayed" time spectrum of these gamma rays. The slow single-channel pulse-height analyzer was set for acceptance of pulses corresponding to 29.4±0.7 kev. The closed circles in Fig. 1 show this "delayed" spectrum for an argon target. It was found that the peak labeled K^{40} did not appear when a $\frac{1}{16}$-inch copper filter was interposed between the target and the detector nor when the gas

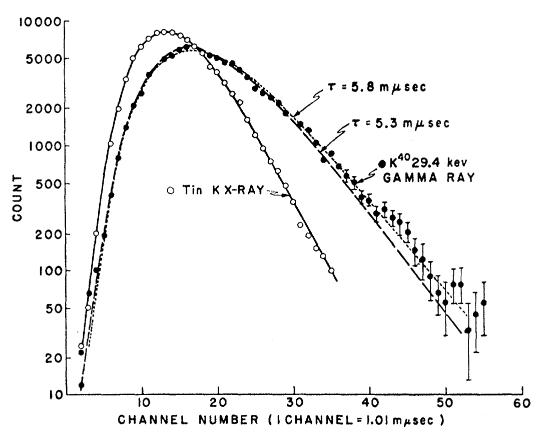

FIG. 1. Time spectrum for tin x-rays (open circles), and the 29.4-kev gamma rays of K^{40} (closed circles). Also shown as dashed lines are computed curves for two assumed values of the mean life. All curves were normalized so as to have the same area.

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target was evacuated. Background corrections on the data were made by subtracting from all points the average number of background counts per channel determined at a time quite different from that at the peak.

The K x-rays of tin, obtained from proton bombardment of a tin target, have an average energy of 26 kev and a mean life of approximately 5×10^{-17} sec. The time spectrum for the tin x-rays is, therefore, a measure of the resolution of the instrument. This "prompt" time spectrum, shown by the open circles in Fig. 1, was obtained with a tin target under conditions identical to those for the argon target. In this case, the observed distribution width of about 11 mμsec at half-maximum is greater than the pulse width of the proton beam, largely because of the statistical fluctuations in the production of photoelectrons by the slowly decaying fluorescence of NaI(Tl) and to a smaller extent because of the spread in the transit times of electrons in the photomultiplier and the effects of amplitude variations of the input pulses on the time-to-pulse-height converter. The best resolution would be obtained if the fast discriminator were set to trigger on the first photoelectron. However, because of the thermionic current from the photocathode, it was necessary to raise the bias of the fast discriminator to reduce the triggering rate. With the prompt curve shown in Fig. 1, it is probable that the discriminator was set to trigger on two photoelectrons.[8] For further reduction of effects of counting rate, the bias for later measurements was raised to require about three photoelectrons to trigger.

III. RESULTS

When the first measurements of the lifetime were made, it was necessary to shut down the accelerator to change targets. Under these conditions, the positions of the peaks produced by the same target were sometimes shifted by as much as 1 mμsec, presumably because of failure of the accelerator to return to the initial operating conditions. Instead of using the centroid-shift method of finding the mean life, we adopted that value of the mean life $1/\lambda$ which produced the best visual fit between the "delayed" time spectrum observed, and the one to be expected from the resolution [as measured by the "prompt" time spectrum $P(t)$], and the decay constant λ. For each trial value of λ, the expected "delayed" time spectrum $F(x)$ was calculated using the expression[9]

$$F(x)=K\int_0^\infty e^{-\lambda t}P(x-t)dt,$$

where K is a constant such that the area under $F(x)$ is equal to the area under the measured "delayed" time spectrum. Figure 1 shows two curves for $F(x)$, one computed for $1/\lambda=5.3$ mμsec and one computed for $1/\lambda=5.8$ mμsec. The average of several sets of data of this type gave a mean life of 5.8 mμsec.

A second set of measurements of the lifetime was made with a target assembly which permitted bombardment of either target without shutting down the accelerator. During a measurement, the targets were interchanged several times to minimize the effects of changes in the accelerator and the electronic equipment. In order to minimize possible spurious time shifts caused by high counting rates, the fast discriminator bias was raised to require about three photoelectrons to trigger. This resulted in a widening of the "prompt" curve to a full width at half maximum of about 16 mμsec. Analysis of these data by the method described above gave a value of 5.4 mμsec for the mean life, in agreement with the value obtained from the difference in position of the centroids of the two curves.

The average value for both sets of data was 5.6 ± 0.5 mμsec for the observed mean life. To obtain the mean life for decay by gamma-ray emission, this result must be corrected for internal-electron-conversion. By extrapolation of Rose's tables,[10] we obtained a total conversion coefficient (assuming an $M1$ transition) of 0.29. The mean life for gamma-ray emission is then 7.2 ± 0.7 mμsec. The corresponding $M1$ transition rate is 0.2 Weisskopf units, well within the usual range of values observed for this quantity. This supports the assumption that the transition is mainly magnetic dipole, in agreement with the proposed decay scheme. The mean life of 7.2 mμsec is also close to the value 9.5 mμsec obtained by J. B. French in an unpublished computation based on the j-j coupling model.

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