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Lifetime and branching ratio of the second excited state of ^{38}K†

N. M. Denkin, R. W. Kavanagh, and G. Bedrosian
W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125
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The lifetime of the second excited state of ^{38}K has been determined to be 12 ± 2 ps using a recoil-distance technique with the reaction ^{24}Mg(^{16}O, pn). The $E2/M1$ branching ratio was found to be (0.96 ± 0.10)% using the reaction ^{35}Cl(α, n) just above threshold. The excitation energies of the first two excited states have been found to be 130.2 ± 0.4 and 458.7 ± 0.3 keV. These results are compared with prior experimental and theoretical work.

[NUCLEAR REACTIONS ^{38}K; ^{24}Mg(^{16}O,pn), E=27.5 MeV; ^{35}Cl(α,n), E=7.31, 7.00 MeV; measured lifetime, recoil distance; γ branching; excitation energies.]

I. INTRODUCTION

Several shell-model calculations[1-4] have been performed for the ^{38}K nucleus, using various forms of the modified surface δ interaction (MSDI) and the Tabakin interaction, with considerably different predictions for decay properties of the low-lying states of ^{38}K (see Fig. 1). In particular, the second excited state at 458.7 keV is variously predicted to have lifetimes ranging from 10 to 170 ps with $E2/M1$ branching ratios ranging from about 0.1 to 14%. Previous experimental determinations[5,9-11] of the lifetime have been contradictory, ranging from 10 to 740 ps, and only an upper limit of 1% has been placed on the relative strength of the $E2$ branch to the ground state.[9] We report here a new lifetime determination and detection of the rare $E2$ transition.

II. LIFETIME MEASUREMENT

Preliminary measurements using a moving-absorber technique, with a somewhat modified existing apparatus[12] and the ^{35}Cl(α, n) reaction, indicated that the lifetime of the second excited state is less than 50 ps. Therefore, a recoil-distance apparatus was constructed, suitable for lifetime measurements in the range 5 to 50 ps. The plunger is driven by a differential screw which moves a stopper uniformly over a range of 0–1.7 mm with an estimated accuracy of about 2 μm when the screw is moved in one direction.

The reaction ^{24}Mg(^{16}O, pn)^{38}K with $E_0 = 27.5$ MeV was used to populate the second excited state; the forward velocity of the ^{38}K is then about 6 μm/ps. A thin flat target substrate was made by stretching a 5000-Å Ni foil over an aperture, following the method described by Gallant,[13] and natural magnesium was then vacuum-evaporated on the down-beam side to a thickness of 160 μg/cm^2.

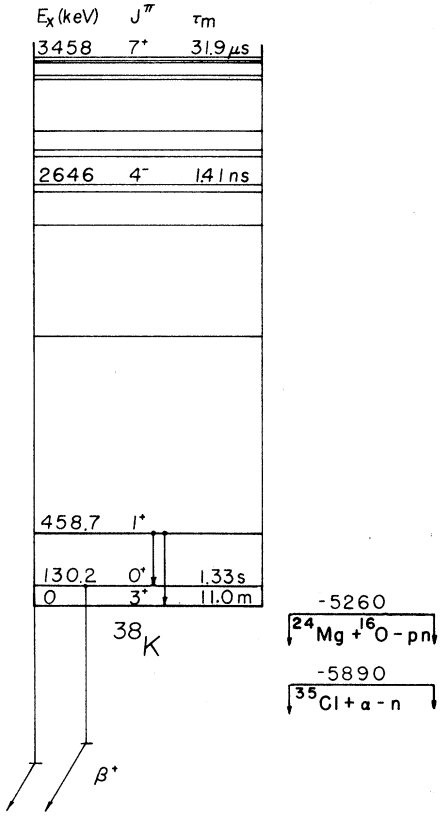

FIG. 1. Abbreviated level diagram of ^{38}K including some of the long-lived excited states. The lifetime of the 2646-keV state was reported in Ref. 5, and that of the 3458-keV state in Ref. 6. The J^π assignments of these states were made in Ref. 7. The lifetime and mass of ^{38}K*(130) were reported in Ref. 8.

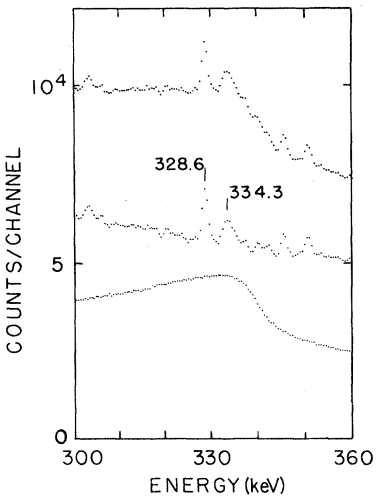

FIG. 2. A typical spectrum, obtained from the ^{24}Mg-(^{16}O,pn) reaction, taken at stopper distance 80 μm. The uppermost curve shows the unprocessed data. The lowest curve shows the annihilation-radiation Compton-edge region from a ^{22}Na calibration run which has been normalized to the same number of annihilation quanta as the raw data. The middle curve is the difference of the other two, with centroids indicated for the fully shifted peak (334.3 keV at 0°) and for the unshifted peak (328.6 keV). A slight shift remains in the "unshifted" energy because of the finite stopping time of the recoiling nucleus in the Au stopper.

The target was fixed in position while a gold-plated (25-μm Au) stopper was moved by the differential screw. The $^{16}O^{5+}$ 120-nA beam, with energy 29 MeV to allow for loss in the Ni foil, was collimated to 3.2 mm through Ta apertures. A 72-cm^3 Ge(Li) was located at 0°, 4.6 cm from the target, with a Ta-Sn absorber inserted to attenuate x rays without seriously reducing the efficiency for the 328-keV γ ray from the decay of the 459-keV state.

A typical spectrum is shown in Fig. 2. The area of the Doppler-shifted peak was difficult to extract because of the rapidly changing background near the Compton edge from the annihilation radiation. This background was removed by subtracting a spectrum from a ^{22}Na source, normalized to the same number of counts in the annihilation peak. After the subtraction, the remaining background was smooth enough that peak-area determination was straightforward. The necessary corrections to the Doppler-shifted peak area and the general analysis of this type of data are discussed in detail by Van Driel *et al.*[5] The total correction applied to the area of the shifted peak, due to the efficiency variation of the detector and to the more forward decay of the moving projectiles, was 1.8%. The ratio of the area of the unshifted peak I_0 to the sum of the areas of both peaks I_0+I_S is equal to the fraction of remaining excited nuclei at the stopping surface (assuming negligible stopping time in Au). Hence we expect this ratio to drop exponentially with increasing target to stopper distance. However, there are excited states at 2.646 and 3.458 MeV, both of which have lifetimes much longer than the second excited state and both of which decay in part through the second state.[5] The result of this is an approximately constant source of ^{38}K(458.7) which provides a long-lived background. Therefore, the data as shown in Fig. 3 were fitted with the function $F(d)=I_0/(I_0+I_S)$ $=(1-A)\exp[-(d-d_0)\beta c\tau_m]+A$ in which A is the constant background, $d-d_0$ is the target to stopper distance, $\beta c=5.3$ μm/ps is the projectile velocity, and τ_m is the lifetime. β is determined from the Doppler shift using the energy difference between the unshifted and shifted peaks as in Fig. 2. In the fitting procedure d_0 was allowed to vary, although it was measured after the runs, by observing the point at which electrical contact was established between the target and the stopper, to test for possible target movement or lack of flatness. The fitted value of d_0 agreed with the measured value. From the best fit, shown in Fig. 3, we find τ_m $=12\pm2$ ps.

III. BRANCHING-RATIO MEASUREMENT

A previous measurement[9] of the $E2$ transition to the ground state indicated a rate less than 1% of the $M1$ transition to the 130-keV state. In the present work, the reaction ^{35}Cl(α,n)^{38}K(458.7) was used to populate the second excited state, with $E_\alpha=7.31$ MeV, 0.26 MeV above threshold. The target, prepared by evaporating 64 μg/cm^2 of

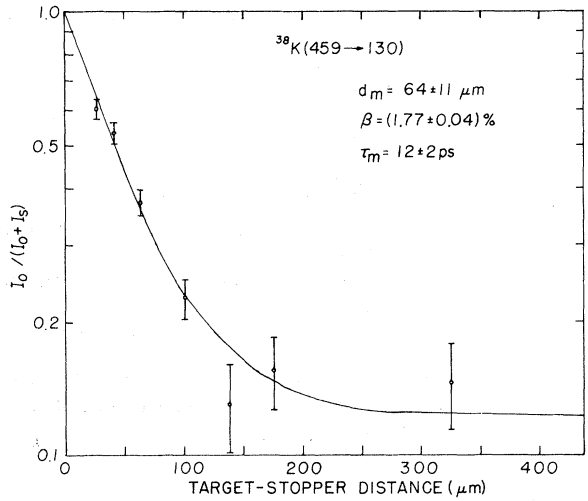

FIG. 3. Decay curve of ^{38}K(458.7) as best fitted to the data obtained with various stopper distances, from spectra typified by Fig. 2.

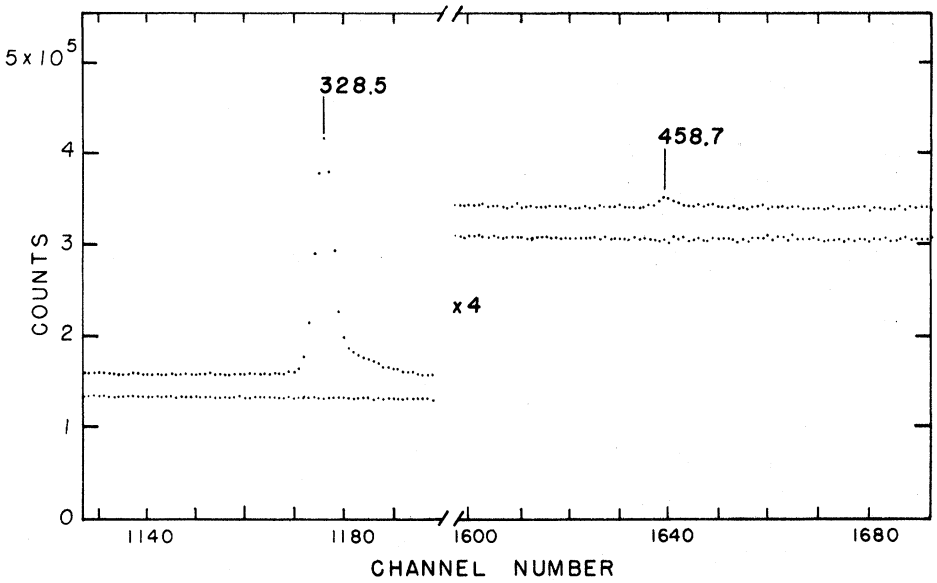

FIG. 4. γ-ray spectra from $^{35}Cl(\alpha,n)^{38}K$, taken at bombarding energies above and below threshold for excitation of the 458.7-keV level. The upper spectrum was obtained at $E_\alpha = 7.31$ MeV, the lower at $E_\alpha = 7.00$ MeV. The photopeaks indicated at 328.5 and 458.7 keV are attributed to decays to the first excited state and to the ground state, respectively. The dispersion is 0.279 keV/channel.

TABLE I. Electromagnetic decays of the second excited state of ^{38}K.

Theory	Interaction	τ_m (ps)	Γ_{M1} (W.u.) [a]	Γ_{E2} (W.u.) [a]
Dieperink and Glaudemans (1969) [b]	Tabakin	11	0.087	1.06
	MSDI [c]	12	0.081	0.97
Dieperink and Brussaard (1969) [d]	Tabakin	10	0.106	1.23
	MSDI [e]	12	0.084	0.63
Evers and Stocker (1970) [f]	MSDI	12.3	0.079	0.47
	MSDIT [g]	23.2	0.042	1.00
	MSDITC [h]	63.3	0.015	1.10
Wildenthal et al. (1971) [i]	MSDI	171	0.0048	4.8
Experiment	**Method**			
Engmann et al. (1971) [j]	Recoil distance	740 ± 160	0.0012	< 0.07
Gordon (1973) [k]	DSA [l] in Xe gas	150 ± 90	0.0059	•••
Hasper and Smith (1973) [m]	DSA in Ca + Ni	> 4	< 0.22	•••
Van Driel et al. (1974) [n]	Recoil distance	10.1 ± 0.9	0.088	•••
This work	Recoil distance	12 ± 2	0.074	4.2
Best value [o]		10.4 ± 0.8	0.085	4.8

[a] Conversion factors to W.u. (Weisskopf units) were taken from Ref. 16.
[b] See Ref. 1.
[c] MSDI denotes modified surface δ interaction.
[d] See Ref. 2.
[e] Quote of private communication from Glaudemans.
[f] See Ref. 3.
[g] MSDIT denotes MSDI including a two-parameter tensor interaction.
[h] MSDITC denotes MSDIT with one of the tensor parameters held constant.
[i] See Ref. 4.
[j] See Ref. 9.
[k] See Ref. 10.
[l] DSA denotes Doppler-shift attenuation.
[m] See Ref. 11.
[n] See Ref. 5.
[o] Combining only the last two measurements.

$BaCl_2$ on a Ta blank, was mounted in a glass tee and inclined at 45° with respect to the beam. The 72-cm^3 Ge(Li) detector was at 90° with an absorber of 1.6 mm of Pb, 0.25 mm of Ta, and 0.25 mm of Sn placed between the target and detector to attenuate x rays. A 25-h run with the beam current about 300 nA resulted in the upper spectrum shown in Fig. 4. The experiment was then repeated at $E_\alpha = 7.00$ MeV which is just below threshold and the lower spectrum was obtained, showing the absence of both the $E2$ and $M1$ transitions. In order to extract the branching ratio, the areas of the peaks must be corrected for variation of the efficiency of the detector and the attenuation in the absorbers. The correction factor was found to be 0.929 ± 0.015 by placing an ^{192}Ir source (which has strong lines at 316.5 and 467.9 keV with relative intensity known[14] to a precision of 1.9%) in the same geometry as the $BaCl_2$ target. The energy calibration was performed using a ^{133}Ba source.[15] The error in the assigned energies is estimated to be less than 0.3 keV.

The area ratio was found to be 0.0103 ± 0.0011 leading to the result

$$\frac{\Gamma_{E2}}{\Gamma_{M1}} = (0.96 \pm 0.10)\% .$$

IV. DISCUSSION

The results of this and prior work are shown in Table I. Combining our result with that of Van Driel *et al.*, we obtain a "best value" for the lifetime of 10.4 ± 0.8 ps. The measurement of Gordon is excluded because of its large relative uncertainty, and the much longer lifetime reported by Engmann *et al.* is assumed to be in error due perhaps to an unidentified contaminant.

In some of the theoretical reports cited in Table I, the transition strengths were not given explicitly. In these cases the transition strengths were calculated from the given lifetime and the branching ratio assuming that the second excited state was at 0.45 MeV as was assumed in the calculations. The lifetimes calculated by Dieperink and Glaudemans for the second excited state have been reduced by a factor of 10 since a recalculation of the lifetime using their published MSDI amplitudes gives a lifetime of 12 and not 120 ps. (Dieperink and Brussaard quote a Glaudemans calculation of this lifetime of 12 ps.) The Tabakin-interaction lifetimes agree quite well with the best measured values, although the calculated $E2$ transition strengths are low by a factor of about 4. The MSDI lifetimes of Dieperink and Glaudemans, Glaudemans (quoted in Ref. 2), and Evers and Stocker are also in reasonable agreement with the experimental values, although the $E2$ transition strengths are low by as much as a factor of 10. Wildenthal *et al.* calculate an $E2$ strength very close to the experimental value, but the $M1$ strength is low by a factor of 19.

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