Decay of the 22-μs isomeric state of $^{38}K^{\dagger}$

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The decay of the 22.5-μs isomer of ^{38}K has been studied by observing the delayed γ rays following the ^{24}Mg(^{16}O, pn)^{38}K and ^{35}Cl(α, n)^{38}K reactions. γ-ray singles and γ-γ coincidence measurements were made and the reaction threshold for production of the isomer was determined for the (α, n) reaction. The 3458-keV metastable state decays by an apparent $E1$ transition ($\alpha_T = 0.58$) to a level at 3420 keV and by an 812-keV transition to a level at 2646 keV. The isomerism is understood in terms of the selection rules for the decay of $E1$ transitions in $T=0$ nuclei. A weak-coupling estimate of the excitation energy of the $7^+ (1f_{7/2})^2$ state in ^{38}K yields a value in excellent agreement with that observed for this isomer.

[RADIOACTIVITY ^{38}K (3458-keV level) [from ^{24}Mg(^{16}O,pn), ^{35}Cl(α,n)]; measured E_γ, I_γ, $T_{1/2}$, γ-γ coin, (α, n) reaction threshold. Natural targets. Ge, Ge(Li), NaI(Tl) detectors.]

I. INTRODUCTION

The self-conjugate nucleus ^{38}K has previously been studied primarily by charged-particle reaction spectroscopy.[1-3] These measurements have yielded spectroscopic factors and l values for several low-lying states but have provided little information about the levels above 3 MeV in excitation energy. Recently, particle-γ coincidence studies[4,5] have significantly extended the level structure of this nucleus, and Hasper, Smith, and Smulders[4] have investigated the levels of ^{38}K to 3.7 MeV by means of α-γ angular correlations following the excitation of levels by the ^{40}Ca(d, α)-^{38}K reaction. In that work it was observed that a small peak in the α-particle spectrum corresponding to an excitation energy of about 3460 keV showed no coincidences with γ-rays and it was suggested that this level must have a lifetime appreciably longer than 50 ns.

This paper describes our investigations of a new metastable state at 3458 keV which has been produced using the ^{24}Mg(^{16}O, pn)^{38}K and ^{35}Cl(α, n)-^{38}K reactions. As this study was being concluded, van Driel *et al.*[6] reported their measurements of this isomeric decay in which the (^{16}O, pn) reaction was used for production of the isomer. The results given here are in good agreement with their work.

II. EXPERIMENTAL PROCEDURES

The 22-μs ^{38}K activity was produced in bombardments of thick magnesium metal targets with 32- to 56-MeV ^{16}O ions or by bombarding either $PbCl_2$ or AgCl with 10- to 16-MeV α particles. The ion beams from the Argonne tandem accelerator were pulsed after acceleration by vertical deflection across a slit by means of an electric field[7] and the decay was observed between beam pulses. γ-ray pulse-height and time information were stored in a magnetic-core memory in 4096 × 16-, 1024 × 64-, or 512 × 128-channel arrays.

The detectors used in these measurements were a 23-cm^3 Ge(Li) spectrometer with 2.9-keV energy resolution full width at half-maximum (FWHM) for the 1332-keV γ ray of ^{60}Co and a 4-cm^3 intrinsic Ge detector having a resolution of 800 eV at the 59-keV γ ray of ^{241}Am. Energy and efficiency calibrations were performed using standardized radioactive sources.

Figure 1 shows γ-ray spectra measured for two equal time intervals following the beam pulse. Except for the peaks attributed to the decay of the 8-min ground state of ^{38}K, all of the labeled γ rays decay with a lifetime of 32.4 ± 0.8 μs ($t_{1/2} = 22.5$ μs). A list of γ rays attributed to this decay is given in Table I. Van Driel *et al.*[6] have also suggested a γ ray at 2187 keV with an intensity approximately 1% that of the 2646-keV γ ray. This transition was not confirmed by the present measurements but it is possible that such a weak γ ray would be undetected due to the background of γ rays in that region.

γ-γ coincidence measurements were performed using the Ge(Li) or Ge detector in conjunction with a 10.2 × 10.2-cm NaI(Tl) detector. Coincidence gates were set on the 2646- and 3420-keV photopeaks in the NaI spectrum. The 38-keV γ ray was observed to be the only γ ray in coincidence with the 3420-keV γ ray (see Fig. 2), while the 774- and 812-keV γ rays were detected in coincidence with the 2646-keV γ ray.

The reaction threshold for formation of the 22-μs isomer by the $^{35}Cl(\alpha, n)^{38}K$ reaction was determined by observing the intensity of the 38-keV γ ray as a function of bombarding energy and integrated beam. Figure 3 illustrates the experimental data. The solid curve represents a best fit of the data to an $(\epsilon-\epsilon_0)^{1/2}$ functional dependence,[8] where ϵ is the bombarding energy and ϵ_0 is the threshold energy of the reaction. The measured reaction threshold of 10.39 ± 0.03 MeV is in excellent agreement with that calculated using the reaction Q value[9] for an excitation energy of 3458 keV for the isomeric state.

III. DECAY SCHEME

The decay scheme deduced from the present measurements is shown in Fig. 4 and is consistent with that proposed by van Driel *et al.*[6] A total conversion coefficient of 0.58 ± 0.18 is determined for the 38-keV transition from an intensity balance and is in excellent agreement with that expected for a pure $E1$ transition, although a predominantly $M1$ transition with some $E2$ admixture cannot be ruled out.

TABLE I. γ rays observed in the decay of 22.5-μs ^{38}K isomer.

Energy (keV)	Relative intensity
37.9 ± 0.2	81 ± 8
773.9 ± 0.3	75 ± 6
811.8 ± 0.3	27 ± 3
2645.9 ± 0.3	100
3420.4 ± 0.4	53 ± 5

A level of 2646 keV has been observed in various charged-particle transfer reactions[1-3, 10] and, although definite spin assignments are not possible, this level could have spin of 2, 3, or 4 and is of apparent negative parity. Our preference for the (4^-) assignment shown on the level scheme will be discussed later.

The 3410- to 3470-keV region appears to be somewhat complicated with at least three levels in this range. The (d, α) reaction study of Jänecke[1] established levels at 3420, 3440, and 3470 keV. The latter level which is only weakly populated in (d, α) probably corresponds to the 3460-keV α-particle group which showed no coincidences with γ rays in the α-γ angular correla-

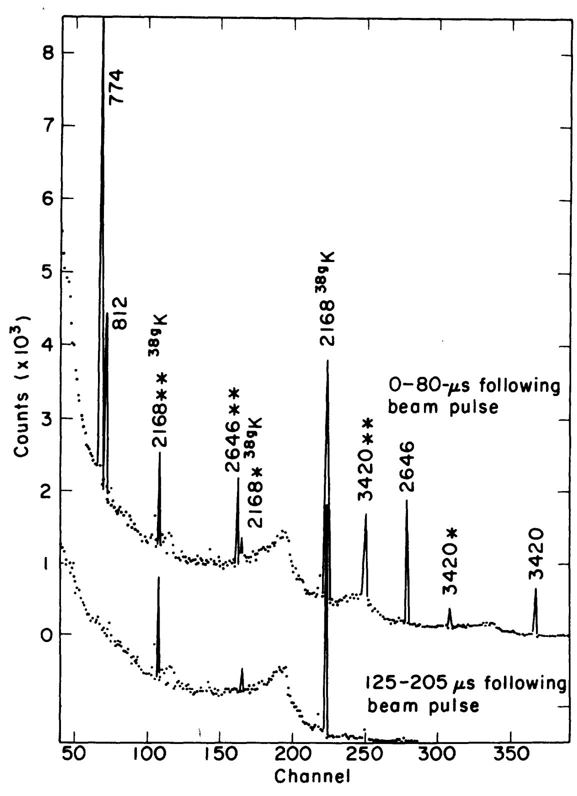

FIG. 1. γ-ray spectra from $^{24}Mg(^{16}O, pn)$ reaction at 44-MeV bombarding energy. Time intervals are indicated and single- and double-escape peaks are denoted by * and **, respectively.

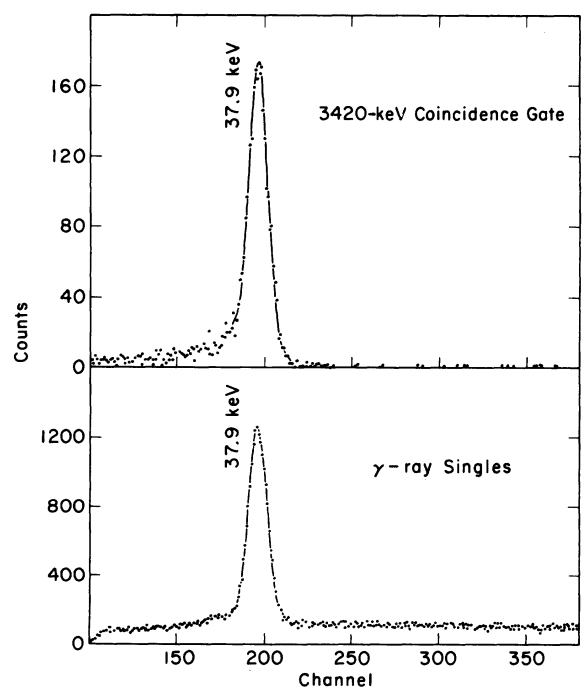

FIG. 2. Low-energy region of the ^{38}K-decay spectrum showing the γ-ray singles spectrum and the spectrum obtained by gating on the 3420-keV γ ray.

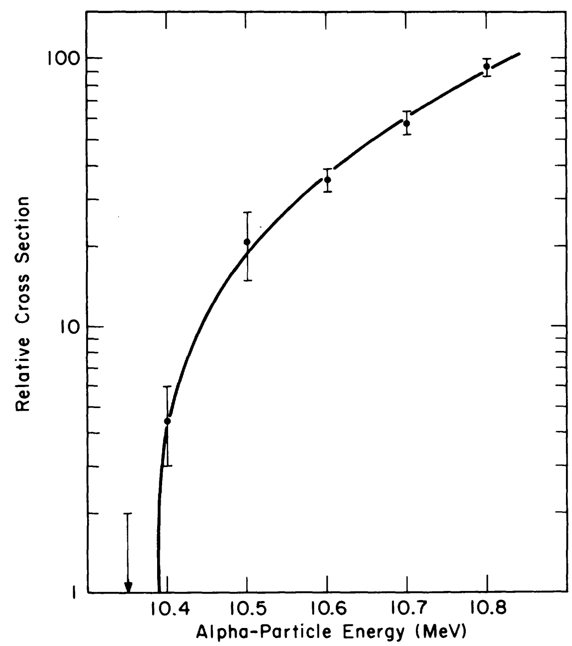

FIG. 3. Threshold determination data from the (α, n) reaction. The curve represents a best fit of the data to an $(\epsilon-\epsilon_0)^{1/2}$ functional dependence.

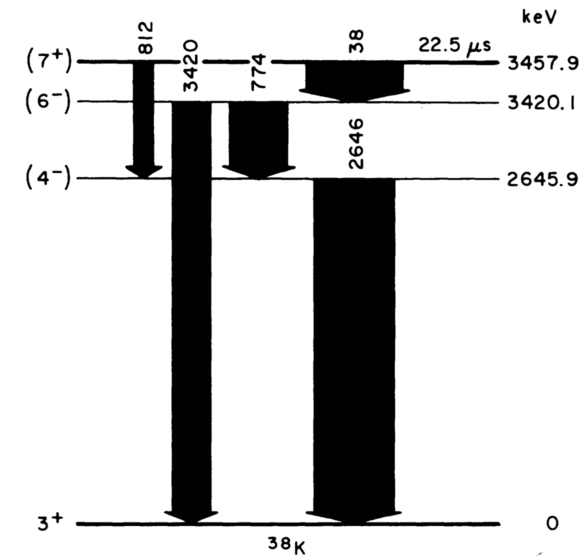

FIG. 4. Decay scheme for the 22.5-μs isomeric state of ^{38}K. Transition intensity is proportional to arrow width.

tion measurements.[4] The level placed by Hasper, Smith, and Smulders[4] at 3416 keV has the same branching pattern for γ decay as the 3420-keV level observed in this study. In addition, a level at approximately 3430 keV has been seen in the $(d, \alpha\gamma)$ and $(^3He, p\gamma)$ work of Collins *et al.*[5] and probably corresponds to the 3443 ± 10-keV level observed by Hasper, Smith, and Smulders. This level is most likely the 2^+, 0 state identified[2,3] in the (d, t) and $(^3He, \alpha)$ reactions.

In very recent measurements[11] using the (α, d) reaction, which has been shown to preferentially populate $(1f_{7/2})^2{}_{70}$ levels, a peak at 3.44 MeV has been observed with cross sections having an angular distribution similar to other known 7^+ states of nuclei in this region. This 7^+ assignment is thus associated with the isomeric level at 3458 keV seen in the present work. The fact that this state is strongly populated in the (α, d) reaction but only weakly populated in the (d, α) reaction is consistent with the two-particle nature of this state. Also the observed greater population of the isomer, relative to the ground-state population of ^{38}K, in the $(^{16}O, pn)$ reaction than that in the (α, n) reaction is consistent with the high-spin assignment. An optical-model calculation with the computer code ABACUS[12] using the parameters for ^{4}He and ^{16}O described in Refs. 13 and 14 yields an average angular momentum of $6\hbar$ for the compound system formed by ^{4}He-ion bombardment while ^{16}O ions can carry in more than twice as much average angular momentum.

IV. DISCUSSION

The decay of the ^{38}K isomer can be understood in terms of the shell model where the isomeric state has the $(1f_{7/2})^2{}_{70}$ configuration. The 7^+ level exhibits two decay modes; one to the probable 4^- level at 2646 keV and another by an $E1$ transition to the level at 3420 keV which is a likely 6^- level. The shell-model calculations of Engelbertink and Glaudemans[15] for $A = 38$ nuclei describes the lowest-lying negative-parity states by the configurations $(2s_{1/2})^4(1d_{3/2})^5\rho$, where ρ denotes a particle in the $1f_{7/2}$ or $2p_{3/2}$ shell. These calculations predict 4^- and 6^- levels at 2.45 and 3.80 MeV, respectively, which receive their main contributions from the $(2s_{1/2})^4(1d_{3/2})^5 \times 1f_{7/2}$ configuration.

In the case of the 38-keV $E1$ transition the observed hindrance factor of 10^6 can be understood by considering two sources. This retardation can be attributed to the characteristic inhibition of $E1$ transitions in a $T = 0$ self-conjugate nucleus[16] and the j forbiddeness[17] associated with the $f_{7/2} \rightarrow d_{3/2}$ transition. The transition rate of the competing unhindered 812-keV (assumed $E3$) transition is in excellent agreement with single-particle estimates.

The excitation energy of an expected 7^+ level in ^{38}K can be estimated for weak coupling by the following calculation[18] where the excitation energy of the 7^+ level is merely the difference between the energy of the $(1d_{3/2})^{-4}(1f_{7/2})^2$ excited state

$$E_{70} = \epsilon_\pi + \epsilon_\nu + 2\epsilon_\pi^{-1} + 2\epsilon_\nu^{-1} + E_{70}[(1f_{7/2})^2] + E_{00}[(1d_{3/2})^{-4}] + 8a + 2\epsilon_C ,$$

and the $(1d_{3/2})^{-2}$ ground-state configuration

$$E_{30} = \epsilon_\pi^{-1} + \epsilon_\nu^{-1} + E_{30}[(1d_{3/2})^{-2}] ,$$

where ϵ_π and ϵ_ν represent the $f_{7/2}$ proton- and neutron-particle energies and ϵ_π^{-1} and ϵ_ν^{-1} are the $d_{3/2}$ proton- and neutron-hole energies, $a = 0.248$ MeV, ϵ_C is the Coulomb interaction energy between the $d_{3/2}$ hole and the $f_{7/2}$ particle (−0.323 MeV in this region), and the remaining terms represent the interaction energies for the respective configurations. The excitation energy is then

$$\Delta E = (\epsilon_\pi + \epsilon_\pi^{-1}) + (\epsilon_\nu + \epsilon_\nu^{-1}) + E_{70}[(1f_{7/2})^2] + E_{00}[(1d_{3/2})^{-4}] - E_{30}[(1d_{3/2})^{-2}] + 8a + 2\epsilon_C .$$

If all energies are calculated relative to closed-shell ^{40}Ca, the numerical values can be obtained from the differences in binding energies of the appropriate nuclei. For example ϵ_π, the binding energy of an $f_{7/2}$ proton to the ^{40}Ca core, is given by the difference between the binding energies of ^{41}Sc and ^{40}Ca. The interaction energy of the $(1f_{7/2})^2{}_{70}$ configuration must also take into account the observed energy (618 keV) of the known 7^+ state in ^{42}Sc. A value of $\Delta E = 3.37$ MeV in remarkable agreement with the measured value of 3.46 MeV is obtained from this calculation and lends support to the $(1f_{7/2})^2{}_{70}$ interpretation of the isomeric state in ^{38}K.

Note added in proof: Recent g-factor measurements[19] of the 22-μs isomeric state in ^{38}K yield a magnetic moment consistent with the $(1f_{7/2})^2{}_{70}$ interpretation for the 3458-keV level.

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