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Mass and Energy Levels of ^{30}Al†

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The ^{30}Si(t, ^{3}He)^{30}Al reaction has been studied with 20-MeV tritons and an Elbek-type spectrograph. The atomic-mass excess of ^{30}Al was determined to be -15.90 ± 0.04 MeV. Excited states of ^{30}Al are observed with $E_x=0.25\pm0.03$, 0.694 ± 0.015, (1.00 ± 0.03), 1.135 ± 0.020, and 1.262 ± 0.015 MeV.

INTRODUCTION

THE isotope ^{30}Al has been observed[1] as a β^- emitter formed in the ^{30}Si(n, p)^{30}Al reaction induced by fast neutrons. Robinson and Johnson[2] report that ^{30}Al has a half-life of 3.27 ± 0.20 sec, $E_{\beta-}(\max)=5.05\pm0.25$ MeV and that it decays primarily to ^{30}Si*(3.507) ($\sim$83%) and ^{30}Si*(2.232) ($\sim$16%), both of which are believed to be $J^\pi=2^+$ states. γ rays with $E_\gamma=2.26\pm0.03$ and 3.52 ± 0.05 MeV were observed: $I(3.52)/I(2.26)=0.64\pm0.06$. β-γ coincidence measurements were not experimentally feasible. The β^- decay to ^{30}Si (0) was not observed: The branch is $<2\%$. Assuming[2] that the β^- branch to ^{30}Si*(2.23) involves $E_{\beta-}(\max)=5.05$ MeV, the ^{30}Al-^{30}Si mass difference is 7.28 ± 0.25 MeV. No energy levels of ^{30}Al have been reported, although a $\tau_{1/2}=72.5\pm1.3$ sec activity observed by Peeters[3] might be ascribed to an isomeric state of ^{30}Al. We decided to study the ^{30}Si(t, ^{3}He)^{30}Al reaction, whose Q value from the mass difference listed above would be -7.26 ± 0.25 MeV, in order to obtain a better determination of the mass of ^{30}Al and some understanding of its level structure, particularly as it bears on the existence of the isomeric state suggested by Peeters.[3]

EXPERIMENTAL PROCEDURES AND RESULTS

A self-supporting ^{30}Si target,[4] 200 μg/cm^2 thick, was bombarded by 20-MeV tritons accelerated in the Los Alamos Tandem Van de Graaff facility. The resultant ^{3}He particles were momentum-analyzed in an Elbek-type spectrograph and were detected using Ilford K-minus-one nuclear plates, shielded from a high α-particle flux by aluminum foils of appropriate thicknesses. Three exposures were made at a magnetic-field setting of 7.558 kG, at angles of 13°, 25°, and 60° to the incident beam. The exposures ranged from 7000 to 3800 μC.

Figure 1 displays the ^{3}He spectrum from the ^{30}Si(t, ^{3}He)^{30}Al reaction at $\theta=13°$. The Q value of the ground-state reaction is found to be -8.52 ± 0.04 MeV. The atomic-mass excess of ^{30}Al is then -15.90 ± 0.04 MeV, and the mass of ^{30}Al is 29.98293 ± 0.00004 amu. The ^{30}Al-^{30}Si mass difference is 8.54 ± 0.04 MeV. The cross section for the ^{30}Si(t, ^{3}He)^{30}Al ground-state reaction ranges between 1 and 10 μb/sr.

Helium-3 groups have also been observed to excited states of ^{30}Al at $E_x=0.25\pm0.03$, 0.694 ± 0.015, (1.00 ± 0.03), 1.135 ± 0.020, and 1.262 ± 0.015 MeV (groups 1–5 on Fig. 1). The assignment of group 3 to ^{30}Al*(1.00) is uncertain because of the low intensity of this group at all three angles of observation. The ^{28}Si(t, ^{3}He)^{28}Al reaction has a $Q_m=-4.616$ MeV.[1] A number of ^{3}He groups corresponding to well-known[1] excited states of ^{28}Al with $E_x\lesssim3.8$ MeV has been observed. These groups, which have energies >11.2 MeV, are not shown in Fig. 1. Their intensities range from about 2% to about 15% of the intensity of the ground-state group at 13°. The low background between the numbered peaks in Fig. 1 probably corresponds to a number of the excited states of ^{28}Al with $3.9\lesssim E_x\lesssim5.2$ MeV. It is not excluded from intensity considerations that group 3 corresponds to one or more of the ^{28}Al states at $E_x\simeq4.9$ MeV. It should be noted that 45 states of ^{28}Al with $E_x<5.2$ MeV have been reported.[1] Of these, 22 have excitation energies in the range 3.9–5.2 MeV.

The ^{30}Al-^{30}Si mass difference obtained in this experiment (8.54 ± 0.04 MeV) is substantially different from that obtained earlier by Robinson and Johnson[2] (7.28 ± 0.25 MeV). The earlier value would lead to a ground-state Q value of -7.26 ± 0.25 MeV for the ^{30}Si(t, ^{3}He)^{30}Al reaction. A search has been made for ^{3}He groups corresponding to this Q value at the three angles of observation. No such groups were observed;

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[1] P. M. Endt and C. Van der Leun, Nucl. Phys. **A105**, 1 (1967).
[2] E. L. Robinson and O. E. Johnson, Phys. Rev. **123**, 1349 (1961).
[3] E. Peeters, Phys. Letters **7**, 142 (1963).
[4] The separated ^{30}Si (95.55% ^{30}Si, 3.78% ^{28}Si, 0.67% ^{29}Si) was furnished by the Stable Isotopes Division of ORNL.

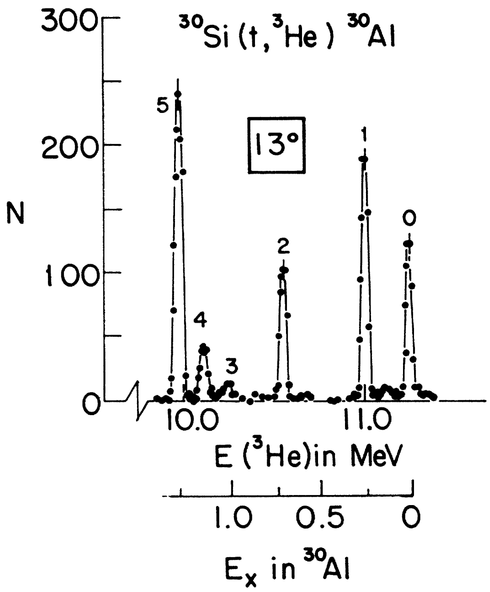

FIG. 1. ^{3}He spectrum for the reaction ^{30}Si(t, ^{3}He)^{30}Al at 13°, $E_t=20.00$ MeV. The group numbers corresponds to levels of ^{30}Al as discussed in the text. The number of ^{3}He tracks N is given per 250-μ-wide "bin" of the photographic plate detector.

the maximum intensity was $\lesssim 5\%$ of the ^{3}He groups corresponding to the ground-state energy reported in this paper. The Robinson-Johnson value for the ^{30}Al-^{30}Si mass difference was based on the assumption that $E_{\beta-}(\max)=5.05\pm0.25$ MeV was related to the decay to ^{30}Si*(2.23). If one assumes instead that the β branch whose energy was determined corresponds to the transition to ^{30}Si*(3.51), the ^{30}Al-^{30}Si mass difference becomes 8.56 ± 0.25 MeV, in excellent agreement with our value. This change in assignment of the β^- branch would require that a second component of the β^- spectrum, corresponding to the transition to ^{30}Si*(2.23), with $E_{\beta-}(\max)=6.3$ MeV, was not observed or was not reported. It appears to us that such a β^- branch is not excluded by the experimental data (see Fig. 2 of Ref. 2). The hypothesis that the 5.05-MeV β branch is to ^{30}Si*(3.51) requires also that 1.28-MeV γ rays due to the 3.51→2.23 cascade be present, with an intensity roughly the same[1] as that of the 3.52-MeV γ rays reported by Robinson and Johnson.[2] The latter do report a strong intensity of 1.32 ± 0.06-MeV γ rays, which could be due to a number of transitions, including the cascade decay mentioned above.

In summary, then, it appears that the energetics of the β-decay results[2] can be understood in terms of the ^{30}Al-^{30}Si mass difference obtained in this work. It would, however, be very interesting to study again the β^- decay of ^{30}Al with the more advanced techniques of β and γ spectrometry that are now available, to determine unambiguously the β branching and to obtain from the ft values a better understanding of the nature of the ground state of ^{30}Al.

On the basis of the preferred β branching[2] to one or both of the $J^\pi=2^+$ states of ^{30}Si, it appears[5] that the ground state of ^{30}Al has $J^\pi=2^+$ or 3^+. We assume that the isomeric state reported by Peeters[3] ($\tau_{1/2}=72.5\pm1.3$ sec) corresponds to the ^{30}Al state at 250 keV reported here [rather, for instance, than to an unresolved state very close ($E_x<30$ keV) to the ground state]. The half-life reported above, if related to $\Delta E=250$ keV, would then correspond most probably to an $E3$ or to an $M3$ transition.[6] It has been suggested[5] that the isomeric state may be a $J^\pi=5^-$ or 6^- state (with the unpaired proton in the $d_{5/2}$ and the unpaired neutron in the $f_{7/2}$ or $f_{5/2}$ shells). The half-life would then be consistent with a 250-keV transition between $J_i^\pi=5^-$ and $J_f^\pi=2^+$ or $J_i^\pi=6^-$ and $J_f^\pi=3^+$.

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[5] G. S. Goldhaber (private communication).
[6] A. H. Wapstra, G. J. Nijgh, and R. Van Lieshout, *Nuclear Spectroscopy Tables* (North-Holland Publishing Co., Amsterdam, 1959).