Title

THE 38Ar(3He,t)38K REACTION AT 40 MeV AND THE EFFECTIVE FORCE FOR (3He,t) REACTIONS

Authors

Bruge, G.
Zisman, M.S.
Bacher, A.D.
et al.

Publication Date

1972-09-01

Submitted to Physics Letters

LBL-1238
Preprint

THE ^{38}Ar(^{3}He, t)^{38}K REACTION AT 40 MeV AND THE EFFECTIVE FORCE FOR (^{3}He, t) REACTIONS

G. Bruge, M. S. Zisman, A. D. Bacher,
and R. Schaeffer

September 1972

AEC Contract No. W-7405-eng-48

DISCLAIMER

THE ^{38}Ar(^{3}He,t)^{38}K REACTION AT 40 MeV AND THE EFFECTIVE FORCE FOR (^{3}He,t) REACTIONS[†]

G. Bruge[††], M. S. Zisman[‡], A. D. Bacher[‡‡], and R. Schaeffer[††]

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

September 1972

The ^{38}Ar(^{3}He,t)^{38}K reaction has been studied with a 40 MeV ^{3}He beam from the Berkeley 88-inch cyclotron. Angular distributions for the first five excited states in ^{38}K have been obtained and compared with DWBA calculations using the central + tensor force model of the (^{3}He,t) reaction. The results indicate that the effective interaction obtained from previous $f_{7/2} \rightarrow f_{7/2}$ unnatural-parity transitions is not adequate to describe the $d_{3/2} \rightarrow d_{3/2}$ unnatural-parity transitions seen here.

— —.—

In recent years increasing use has been made of the (^{3}He,t) reaction as a spectroscopic tool [1]. The emphasis of these studies has generally been to attempt a microscopic description of the reaction in mass regions near closed shells, where comprehensive shell model calculations are available. From previous attempts [2] at a microscopic treatment of the (^{3}He,t) reaction it is known that a tensor term is required [3,4] in the effective interaction

$$v = [V_c f(r)(1 + \vec{\sigma}_1\vec{\sigma}_2) + V_T g(r) S_{12}]\vec{\tau}_1\vec{\tau}_2$$

[†] Work performed under the auspices of the U. S. Atomic Energy Commission.

[††] Present and Permanent Address: CEN Saclay, 91 Gif-sur-Yvette, France.

[‡] Present Address: Physics Department, University of Washington, Seattle, Washington 98105.

[‡‡] Present Address: Physics Department, Indiana University, Bloomington, Indiana 47401.

in order to reproduce the observed [5] preference for the higher L-value in the experimental angular distributions for unnatural-parity transitions.

Recent calculations [4] have also suggested that there are two distinct types of (^{3}He,t) transitions which should show different sensitivity to the tensor term. These types are characterized by the shell model states (j and j') involved in the transition:

$$\left.\begin{array}{l} j = \ell + 1/2 \rightarrow j' = \ell' + 1/2 \\ j = \ell + 1/2 \rightleftarrows j' = \ell' - 1/2 \end{array}\right] \quad \text{Type 1}$$

$$j = \ell - 1/2 \rightarrow j' = \ell' - 1/2 \qquad \text{Type 2}$$

For Type 1 transitions (e.g., $f_{7/2} \rightarrow f_{7/2}$) the calculated angular distributions for unnatural-parity states depend almost entirely on the tensor strength, although comparison with the experimental data does determine an upper limit for the central term [4]. For Type 2 transitions (e.g., $p_{1/2} \rightarrow p_{1/2}$ or $d_{3/2} \rightarrow d_{3/2}$) on the other hand, the calculated angular distributions [4] depend mainly on the central force, although the tensor force contribution is not negligible.

Unfortunately, the only Type 2 transitions studied experimentally [6], $p_{1/2} \rightarrow p_{1/2}$ in ^{14}C(^{3}He,t)^{14}N and ^{14}N(^{3}He,t)^{14}O, indicated that neither a pure central [6] nor a central + tensor [7] force could reproduce the shape of the observed angular distributions. Whether the fault lies with the optical model treatment or with an inadequate description of the transition operator is not clear. However, the measurements do suggest [7] that the central force required for Type 2 unnatural-parity transitions is about four times stronger than the upper limit determined [4] from Type 1 transitions. In order to investigate further this apparent difference between the two types of (^{3}He,t) transitions we have studied the ^{38}Ar(^{3}He,t)^{38}K reaction.

The experiment was performed with a 40 MeV ^{3}He beam from the Berkeley 88-inch cyclotron. The target was argon gas (enriched to 94.4% ^{38}Ar) at a pressure of 120 Torr which was contained in a cell having a thin (0.68 mg/cm^2) nickel entrance foil and a 2.1 mg/cm^2 Havar exit foil. Tritons were detected with telescopes consisting of 0.25 mm ΔE and 3 mm E detectors which fed a Goulding - Landis particle identifier [8]. A triton spectrum at $\theta_\ell = 14°$ is shown in fig. 1. The overall resolution is 75 keV FWHM. Angular distributions for the first five levels of ^{38}K from $\theta_{c.m.} = 11°$ to $50°$ are shown in fig. 2. Only these five states will be considered here since their spins and parities are already known [9] and they are well separated in this experiment.

According to the wave functions of Dieperink and Glaudemans [10], or those of Wildenthal et al. [10], which reproduce the observed β transition rates rather well, three of the five ^{38}K levels below 2.40 MeV [3^+ (g.s.), 0^+ (0.13 MeV), and 2^+ (2.40 MeV)] are built mainly from the $(d_{3/2}^{-2})$ configuration, while the other two levels [1^+ (0.46 MeV) and 1^+ (1.70 MeV)] are composed of $(d_{3/2}^{-2})$, $(d_{3/2}^{-1}\ s_{1/2}^{-1})$, and other components. The shell model picture should be accurate for ^{38}K since the lowest 2p - 4h 3^+ state should not appear until about 3 MeV.

The two natural-parity states observed below 2.40 MeV in ^{38}K are both populated mainly with a $d_{3/2} \rightarrow d_{3/2}$ (Type 2) transition. The interaction responsible for these transitions is well-known: the central force dominates the scattering amplitude with strengths, determined from earlier work [4], of about 6-7 MeV for a 0^+ and about 9 MeV for a 2^+ transition. (The J-dependence of V_c has been discussed previously [1,2,4].) Our analysis yields $V_c(0^+) = 6$ MeV. The calculated 0^+ angular distribution shown in fig. 2a is good agreement with experiment, except for an angular shift of about 2°. On the other hand, the 2^+ prediction (fig. 2d) fails to reproduce the observed angular distribution of the 2.40 MeV level. However, since this angular distribution does not have a typical diffraction pattern, it is difficult to fit with any single L transfer. Lack of structure in 2^+ angular distributions has been observed previously [5]. The curve shown in fig. 2d was calculated with $V_c(2^+) = 11$ MeV, which is in rough agreement with the expected strength. The calculations of Toyama [11], indeed, show that 2^+ states populated by the (^{3}He,t) reaction should not have a pronounced diffraction pattern, due to two-step processes such as (^{3}He,α) + (α,t).

The unnatural-parity states with the largest admixtures of the $(d^{-2}_{3/2})$ component are the 3^+ ground state (90%) and the 1^+ state at 1.70 MeV (50%). Let us consider first the transition to the 3^+ ground state which is typical of Type 2. For a $0^+ \rightarrow 3^+$ transition of Type 1, (for example ^{48}Ca → ^{48}Sc(3^+)) the contribution of the tensor force dominates, whereas for Type 2 transitions, the central force is the most important one. Within the central + tensor model, the requirement of an $L = J + 1$ angular distribution in Type 1 transitions implies an upper limit for $V_c/V_T \leqslant 3$ (the central force leads to an $L = J - 1$ pattern and the tensor force to one with $L = J + 1$), predicting, therefore, $\sigma(^{48}\mathrm{Sc},3^+)/\sigma(^{38}\mathrm{K},3^+) \geqslant 40$. Checking this prediction, which was our main motivation for doing the ^{38}Ar(^{3}He,t)^{38}K experiment, leads to $\sigma_{\mathrm{exp.}}(^{48}\mathrm{Sc},3^+)/\sigma_{\mathrm{exp.}}(^{38}\mathrm{K},3^+) \approx 6$, which is in strong disagreement with the theory.

This discrepancy might come from a poor choice of either the bound state wave function or the transition operator. One would, however, need a very large amount of 2p - 4h admixture in the ^{38}K ground state in order to account for this difference in strength. This is unlikely since the second 3^+ state lies at much higher energy, but cannot be completely ruled out. (In ^{42}Sc, where the 4p - 2h states are below 1 MeV, the 4p - 2h admixtures affected the calculated cross sections to the "$f^2_{7/2}$ states" by no more than a factor of two.) Our particular choice of the radial shape of the interaction also does not seem to be responsible for the discrepancy. The radial shape is generally rather unimportant, provided the strengths of the different force components (V_c and V_T) are adjusted as was done here. (An illustration of this property for the central force can be found in ref. [2].) Another possibility is, therefore, the failure of the central + tensor force model itself. An improved fit (fig. 2e) can be obtained for the ^{38}K 3^+ state by renormalizing the central force, i.e. using $V_c = 18$ MeV, and $V_T = 2.3$ MeV. Of course, this force is not compatible with Type 1 transitions.

For the 1.7 MeV 1^+ state (fig. 2c), it is possible to obtain an acceptable fit within the central + tensor force model by renormalizing the central force ($V_c = 6$ MeV, $V_T = 9.3$ MeV), which is compatible with the $f_{7/2} \rightarrow f_{7/2}$, $0^+ \rightarrow 1^+$ transition. However, for Type 1 transitions it is difficult to distinguish between the calculated $L = 0$ pattern (from the central force) and the $L = 2$ pattern (from the tensor force), since they have almost identical shapes. Therefore an upper limit on V_c/V_T cannot be determined accurately from $0^+ \rightarrow 1^+$ Type 1 transitions. The 0.46 MeV 1^+ state (fig. 2b), which is produced by a destructive interference of $d_{3/2} \rightarrow d_{3/2}$, $d_{3/2} \rightarrow s_{1/2}$ and $d_{3/2} \rightarrow d_{5/2}$ transitions, has an $L = 1$ shape rather than an allowed $L = 0$ or $L = 2$ pattern. This discrepancy is also serious and suggests that the transition may be dominated by processes such as (^{3}He,α) + (α,t) [12] for which $L = 1$ is allowed. This two-step mechanism does appear to explain [12] the $0^+ \rightarrow 0^+$, $L = 1$ transitions seen by Hinrichs et al. [13].

The influence of the choice of optical parameters on these results was studied rather extensively. In order to properly reproduce the slope of the experimental angular distributions it was found essential to use high energy

^{3}He parameters (taken from 30-35 MeV ^{3}He scattering) [14], but all of the optical potentials used, including one for 12 MeV triton scattering [15], produce the same typical diffraction patterns. The calculations reported here were made using the 35 MeV ^{3}He parameters of ref. [14]. Since the correction for the asymmetry potential has no effect on the calculated angular distributions, it was not used.

In conclusion, the ^{38}Ar(^{3}He,t)^{38}K experiment shows that the usual [2,3,4] central + tensor model for the (^{3}He,t) transition operator is insufficient to reproduce Type 2 transitions. New terms need to be included in the reaction mechanism, especially those arising from the (^{3}He,α) + (α,t) process which has already shown a large improvement for some (^{3}He,t) transitions [11,12]. A more complete and detailed calculation is being performed to interpret the higher-lying states in ^{38}K, including the (^{3}He,α) + (α,t) and other two-step contributions.

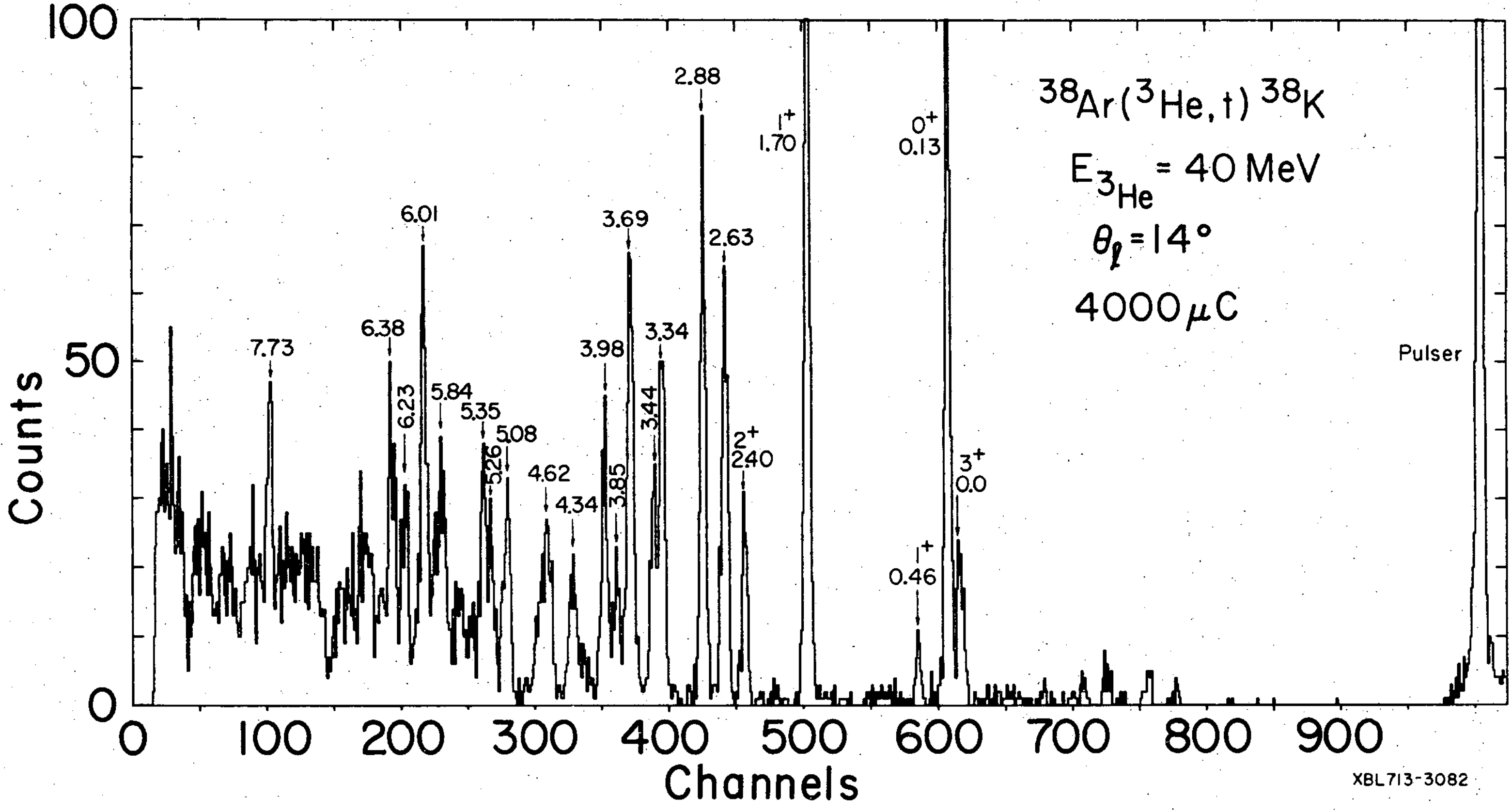
REFERENCES

1. See, for example, Argonne National Laboratory Informal Report No. PHY-1970A, January, 1970, (unpublished) and references contained therein.
2. P. Kossanyi-Demay, P. Roussel, H. Faraggi, and R. Schaeffer, Nucl. Phys. A148 (1969) 181.
3. E. Rost and P. D. Kunz, Phys. Letters 30B (1969) 231.
4. R. Schaeffer, Nucl. Phys. A164 (1971) 145.
5. G. Bruge, A. Bussiere, H. Faraggi, P. Kossanyi-Demay, J. M. Loiseaux, P. Roussel, and L. Valentin, Nucl. Phys. A129 (1969) 419.
6. G. C. Ball and J. Cerny, Phys. Rev. 177 (1969) 1466.
7. R. Schaeffer, unpublished calculations based on the data in ref. 6.
8. F. S. Goulding, D. A. Landis, J. Cerny, and R. H. Pehl, Nucl. Instr. Methods 31 (1964) 1.
9. J. Janecke, Nucl. Phys. 48 (1963) 129.
10. A. E. L. Dieperink and P. W. M. Glaudemans, Phys. Letters 28B (1969) 531; B. H. Wildenthal *et al.*, Phys. Rev. C4 (1971) 1267.
11. A. Toyama, Phys. Letters 38B (1972) 147.
12. R. Schaeffer and G. Bertsch, Phys. Letters 38B (1972) 159.
13. R. A. Hinrichs, R. Sherr, G. M. Crawley, and I. Proctor, Phys. Rev. Letters 25 (1970) 829.
14. J. W. Leutzelschwab and J. C. Hafele, Phys. Rev. 180 (1969) 1023.
15. H. W. Barz, K. Hehl, C. Riedel, and R. A. Broglia, Nucl. Phys. A122 (1968) 625.

FIGURE CAPTIONS

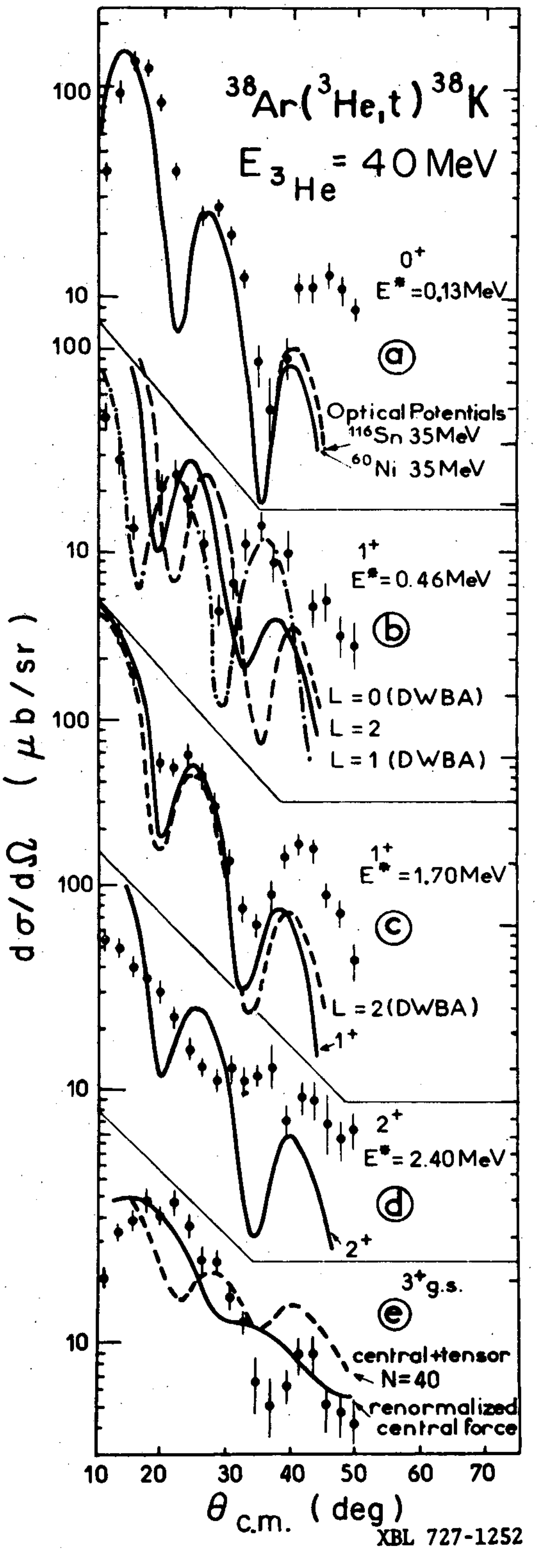
Fig. 1. Triton energy spectrum from the $^{38}Ar(^{3}He,t)^{38}K$ reaction at $\theta_{\ell} = 14°$.

Fig. 2. Angular distributions of the first five states in ^{38}K. The full line curves correspond to calculations using wave functions obtained by Dieperink and Glaudemans [10]. The curves marked DWBA are intended to be typical for the L value assigned to them in the figure, their normalization being arbitrary. The L = 0 (DWBA) and L = 2 (DWBA) patterns shown in b and c are the same as the full-line curves in a and d, respectively. The L = 1 (DWBA) curve was obtained by arbitrarily assuming a $1d_{3/2} \rightarrow 2p_{3/2}$ (1^{-}) transition and the same force as for the L = 2 calculation. A macroscopic model would have given similar patterns. The label "central + tensor" in e refers to the force parameters of ref. [12], and "renormalized" refers to $V_c = 18$ MeV, $V_T = 2.3$ MeV as explained in the text.



XBL713-3082

Fig. 1



XBL 727-1252

Fig. 2

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720