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(t,α) reaction on ^{124}Te, ^{126}Te, ^{128}Te, and ^{130}Te nuclei

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Differential cross section angular distributions have been measured for the first few states in each residual nucleus in the ^{124,126,128,130}Te$(t,\alpha)^{123,125,127,129}$Sb reactions at $E_t = 16$ MeV. The angular distributions for the spin-orbit pair $5/2^+$ and $3/2^+$ have more structure at this energy than those at $E_t = 12$ MeV, but their shapes do not exhibit sufficient J dependence to distinguish between the two spins. Distorted-wave Born approximation calculations reproduce the cross sections quite well. Relative spectroscopic factors, normalized to the sum rule limit, are obtained and these compare well with those obtained in other studies.

[NUCLEAR REACTIONS ^{124,126,128,130}Te$(t,\alpha)^{123,125,127,129}$Sb, $E_t = 16$ MeV, measured $\sigma(E_\alpha,\theta)$, DWBA calculations, Spectroscopic factors.]

To study proton hole states of nuclei, it is convenient to use the simple (t,α) and $(d,{}^3\text{He})$ proton pickup reactions and these have been employed in many such studies. Unfortunately, with tritons of energies previously available, the (t,α) angular distributions for heavy and medium-heavy nuclei did not show any J dependence. It was thus difficult to assign J values to the energy levels. The $(d,{}^3\text{He})$ reaction, on the other hand, requires a deuteron beam of considerably higher energy (~50 MeV) than has been available in most nuclear research laboratories possessing the high resolution beam and particle detection systems necessary to study heavy nuclei. To study such proton hole states in the Sb nuclei, Conjeaud *et al.*[1] used the (t,α), and Auble *et al.*[2] used the $(d,{}^3\text{He})$ reac-

TABLE I. Spectroscopic factors.

Reaction	Final state (J^π)	Excitation energy (MeV)	Spectroscopic factors (C^2S)[a] Present study	(t,α) Ref. 1	$(d,{}^3\text{He})$ Ref. 2
^{124}Te$(t,\alpha)^{123}$Sb	$\frac{7}{2}^+$	g.s.	1.59	1.45	
	$\frac{5}{2}^+$	0.160	0.22	0.28	
	$\frac{3}{2}^+$	0.541	0.14	0.22	
	$\frac{1}{2}^+$	0.720		0.04	
^{126}Te$(t,\alpha)^{125}$Sb	$\frac{7}{2}^+$	G.S.	1.68	1.45	1.44
	$\frac{5}{2}^+$	0.332	0.20	0.43	0.34
	$\frac{3}{2}^+$	0.643	0.09	0.12	0.18
	$\frac{1}{2}^+$	0.912		0.03	0.06
^{128}Te$(t,\alpha)^{127}$Sb	$\frac{7}{2}^+$	g.s.	1.82	1.65	1.56
	$\frac{5}{2}^+$	0.498	0.13	0.23	0.27
	$\frac{3}{2}^+$	0.776	0.03	0.08	0.14
	$\frac{1}{2}^+$	1.180		0.02	0.03
^{130}Te$(t,\alpha)^{129}$Sb	$\frac{7}{2}^+$	g.s.	1.85	1.75	1.68
	$\frac{5}{2}^+$	0.640	0.06	0.20	0.21
	$\frac{3}{2}^+$	0.910		0.05	0.08
	$\frac{1}{2}^+$	1.450			0.03

[a] These spectroscopic factors (C^2S) are normalized to the sum rule limit (2). See text for details.

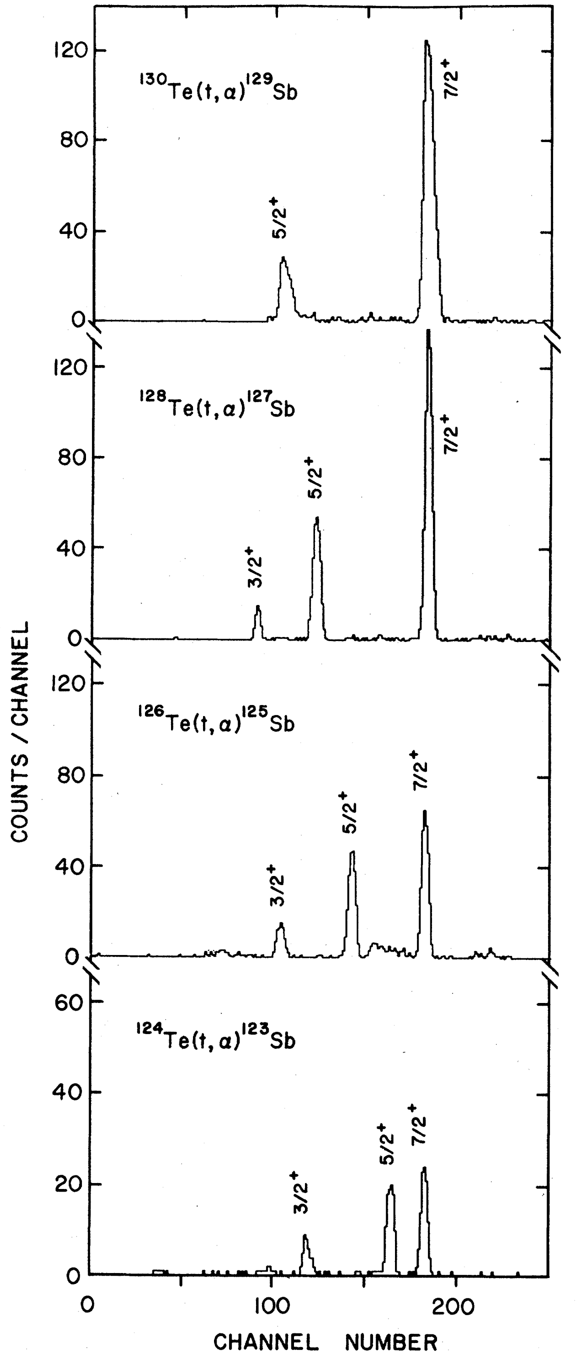

FIG. 1. Typical spectra from the ^{124,126,128,130}Te(t,α)^{123,125,127,129}Sb reactions at E_t = 16 MeV and $\theta_{\rm Lab}$ = 25°.

tion. In the Te(t,α)Sb reaction[1] at $E_t = 12$ MeV, the angular distributions for states having the same L but different J values had identical shapes, e.g. the $\frac{5}{2}^+$ and $\frac{3}{2}^+$ states in the Sb isotopes. The purpose of the present study was to see whether the same Te(t,α)Sb reaction but at a higher triton beam energy would exhibit enough J dependence in the angular distributions to permit unambiguous spin assignments to such "spin-orbit" pairs.

The ^{124,126,128,130}Te(t,α)^{123,125,127,129}Sb reactions were performed at the McMaster University tandem Accelerator Laboratory with a 16 MeV triton beam from the sputter-source and FN tandem accelerator system. The maximum beam on target was ~150 nA. The target thicknesses were ~31, 108, 97, and 157 μg/cm^2 for the ^{124}Te, ^{126}Te, ^{128}Te, and ^{130}Te targets, respectively. The reaction products were analyzed in an Enge split-pole magnetic spectrograph and were detected by a delay line counter at the focal plane. This delay line counter is an MSU type[3] detector adapted for use at the McMaster University spectrograph.[4] The overall resolution for the α spectra was ~30 keV full width at half maximum (FWHM). Typical spectra from these reactions at $\theta_{\rm Lab} = 25°$ are shown in Fig. 1. The angular distributions for the states shown in Fig. 1 in each residual Sb nuclei are shown in Fig. 2. The excitation energies quoted in Table I are from Refs. 2, 5, and 6, and our values agree within 5 keV of these.

The differential cross sections obtained in the present study are shown in Fig. 2. These (t,α) angular distributions have more structure and steeper slopes than those observed in a similar (t,α) reaction study at $E_t = 12$ MeV.[1] The shapes of the angular distributions for the $\frac{5}{2}^+$ and $\frac{3}{2}^+$ states are similar and they do not show any J dependence at this incident energy. However, the shapes of the $L = 4$ ($J^\pi = \frac{7}{2}^+$) and $L = 2$ ($J^\pi = \frac{5}{2}$ or $\frac{3}{2}^+$) angular distributions are different.

The solid and dashed lines in Fig. 2 are the distorted-wave Born approximation (DWBA) calculations with the optical model parameter sets $T1A1$ and $T3A1$ of Table II, respectively. As shown in Fig. 2, the triton parameter set $T1$ produced the best DWBA fits to the Te(t,α)Sb reaction data. However, set $T2$ produces the best fits to the ^{A}Te(t,d)$^{A+1}$Te reaction cross sections.[7] $T3$ is a compromise set between $T1$ and $T2$, which would reproduce both the (t,α) and (t,d) cross sections reasonably well. The parameter sets $T1$ and $T2$ are from Refs. 1 and 8, respectively. The set $A1$ is from Ref. 9.

As the reaction strength of the normalization factor for the (t,α) reaction is not well determined, it is difficult to obtain absolute spectroscopic factors. Since there are two extra protons in Te($Z = 52$) outside the closed core of $Z = 50$ that can distribute themselves among the $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$, and $1h_{11/2}$ orbitals to form the ground states of the Te isotopes, the sum rule

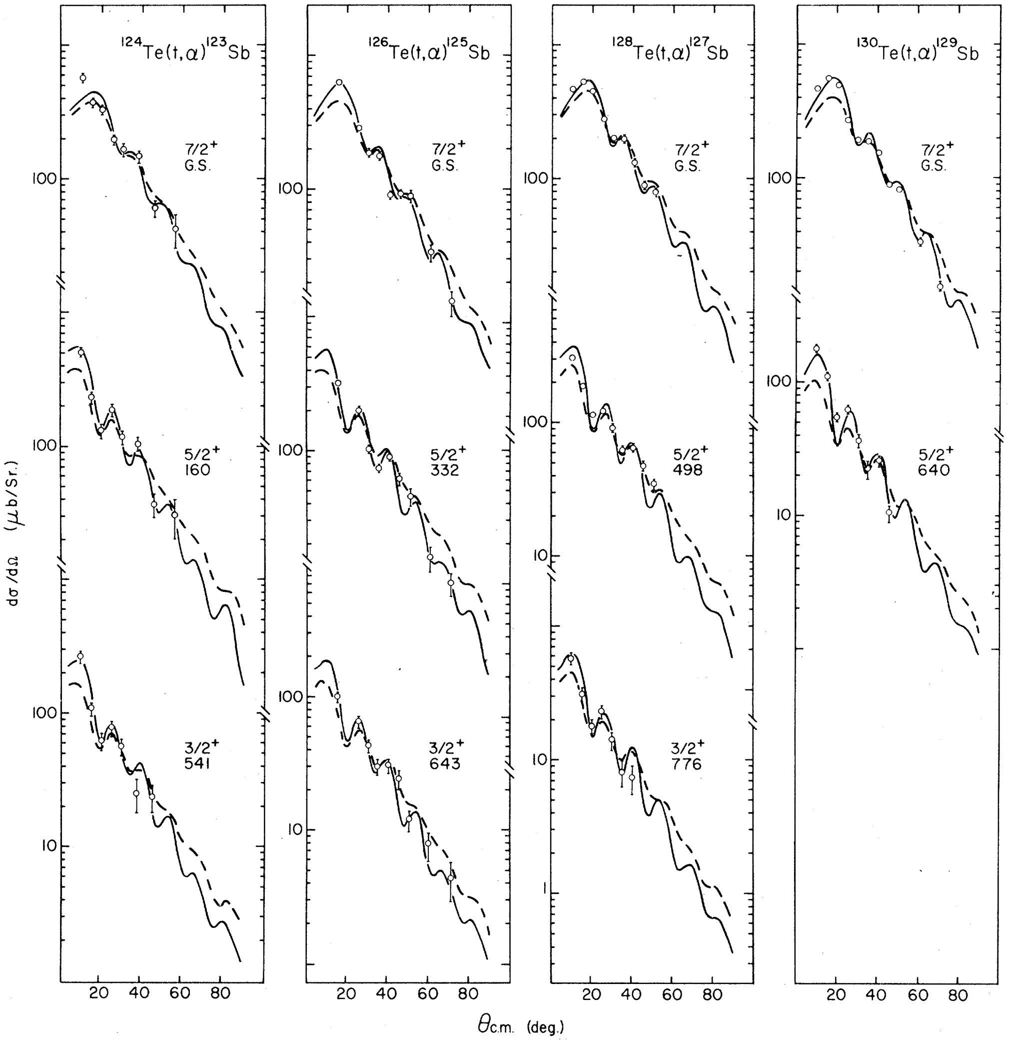

FIG. 2. The differential cross section angular distributions for ^{124,126,128,130}Te$(t,\alpha)^{123,125,127,129}$Sb reactions at E_t =16 MeV. The solid and dashed lines are the DWBA calculations with parameter sets $T1A1$ and $T3A1$ of Table II, respectively.

TABLE II. Optical model parameters. The asterisk refers to an adjustment to reproduce the proton binding energy.

Set	Ref.	V_R (MeV)	r_R (fm)	a_R (fm)	λ (Thomas)	W_V (MeV)	r_I (fm)	a_I (fm)	r_c (fm)
$T1$	a	153.0	1.35	0.889		20.8	1.42	0.889	1.25
$T2$	b	153.0	1.24	0.70		16.4	1.42	0.89	1.25
$T3$	c	153.0	1.30	0.76		18.6	1.42	0.89	1.25
$A1$	d	219.3	1.395	0.549		31.8	1.395	0.549	1.3
$P1$		*	1.25	0.65	25.0				

[a] Ref. 1.
[b] Ref. 7.
[c] Present work.
[d] Ref. 9.

limit of the spectroscopic factors for the Te(t,α)Sb reaction is 2. Thus, only the relative spectroscopic factors normalized to the sum rule limit were obtained from the present calculations. These are shown in column 4 of Table I. The spectroscopic factors for the ground state transitions are ~15% higher than those of Refs. 1 and 2, and they are lower for other states. Nevertheless, on the average, they are quite similar.

Some preliminary calculations indicate that there will be more structure, but still very little J dependence in the angular distributions for Te(t,α)Sb reactions even at $E_t = 35$ MeV. However, the analyzing powers for these reactions will be large even at lower beam energies and will have opposite phases for a spin-orbit pair, such as $\frac{5}{2}^+$ and $\frac{3}{2}^+$ states. Hence the $(\vec{t},\alpha)$ reaction with polarized tritons would be necessary for unambiguous spin assignments to be made.

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